November 17, 1887.

Professor G. G. STOKES, D.C.L., President, in the Chair.

An Address to the Queen upon the completion of the fiftieth year of her reign, which on June 27th, during the recess of the Society, had been graciously received by Her Majesty from the hands of the President, was read from the Chair.

In pursuance of the Statutes, notice of the ensuing Anniversary Meeting was given from the Chair.

Sir James Cockle, Dr. Huggins, Dr. Rae, Mr. Stainton, and Mr. Symons were by ballot elected Auditors of the Treasurer's accounts on the part of the Society.

The Presents received were laid on the table, and thanks ordered for them.

The following Papers were read:—

I. "Researches on the Spectra of Meteorites. A Report to the Solar Physics Committee." Communicated to the Royal Society at the request of the Committee. By J. NORMAN LOCKYER, F.R.S.

Preliminary Note. Received October 4, 1887.

Some years ago I commenced a research on the spectra of carbon in connexion with certain lines I had detected in my early photographs of the solar spectrum. I have been going on with this work at intervals ever since, and certain conclusions to which it leads, emphasising the vast difference between the chemical constitution of the sun and of some stars, recently suggested the desirability of obtaining observations of the spectra of meteorites and of the metallic elements at as low a temperature as possible.

I have latterly, therefore, been engaged on the last-named inquiries. The work already done, read in conjunction with that on carbon, seems to afford evidence which amounts to demonstration on several important points.

I think, therefore, that it may be of use to state some of the conclusions at once, though the researches are still very far from complete, and though they must be given with great reserve, as the astronomical observations with which I have had to compare my laboratory work have been frequently made under conditions of very great difficulty. The evidence before me suggests the following conclusions:—

(1.) The luminous phenomena, not only of comets, as determined on other grounds by Schiaparelli, but of all bodies in the heavens shining by their own light, except stars like the Sun and Sirius, are produced by meteorites in various aggregations and at different temperatures.

(2.) The temperature of the meteorites in some cases is about that of the oxyhydrogen flame.

(3.) Among the chief sources of fluting absorption in many "stars" are manganese vapours at a low temperature.

(4.) The bright flutings of carbon in some "stars," taken in conjunction with their absorption phenomena, indicate that widely separated meteorites at a low temperature are involved.

(5.) Olivine and kindred minerals appear to be chief bright-line-producing agents in the "nebulæ."

(6.) New stars are produced by the clash of meteor swarms, the bright lines seen being low temperature lines of those elements in meteorites the spectra of which are most brilliant at a low stage of heat.

(7.) The spectrum of the hydrogen in the case of the nebulæ seems to be due to low electrical excitation, as happens with the spectrum of carbon in the case of comets. Sudden changes from one spectrum to another are seen in the glow of meteorites in vacuum tubes, when a current is passing.

Addendum. Received November 15, 1887.

In anticipation of the detailed account and maps which are now being prepared, I beg to append a brief statement showing the line of investigation adopted, and how the various intercomparisons of laboratory and observatory work which have suggested the above general views have been made.

Experiments upon which the foregoing Conclusions depend.

A. *Experiments upon Carbon.*

The main conclusions which may be stated here are that there are two systems of flutings which depend upon temperature only. At low temperatures all compounds of carbon give a set of simple flutings, the brightest of which are at wave-lengths 4510, 4830, 5185, and 5610. At higher temperatures there is a series of compound flutings, the brightest edges of which are at wave-lengths 4380, 4738, 5165, and 5640. In the case of compounds of carbon with hydrogen, there is an additional fluting at wave-length 4310, and this is the only criterion for the presence of hydrocarbons among the flutings shown on the map (see Map 3).

B. *Experiments upon the Luminous Phenomena of the various Metals volatilised in the Bunsen Burner and the Oxy-coal-gas Blowpipe Flame as compared with the Phenomena seen at higher Temperatures.*

The main conclusions are that certain lines, bands, and flutings are seen in the bunsen burner, that a larger number is seen in the flame, and that the total number seen in the burner and flame is small.

The order of visibility in the bunsen is, roughly—

Lines	Mg Na Li Tl Sr Ba Ca K Mn Bi
Bands	Ca Sr Ba
Flutings	Mg Mn

All the observations both of bunsen and oxyhydrogen flame may be condensed as follows:—

In metals of the alkalies	Na K Li
,, ,, alkaline earths	Ca Sr Ba
In magnesian metals	Mg Zn Cd
In iron metals........................	Fe Ni Co Mn Cr
In metals which yield acids	Bi Ti W
In copper metals	Cu Tl
In noble metals	Ag Hg
In earthy metals......................	Ce

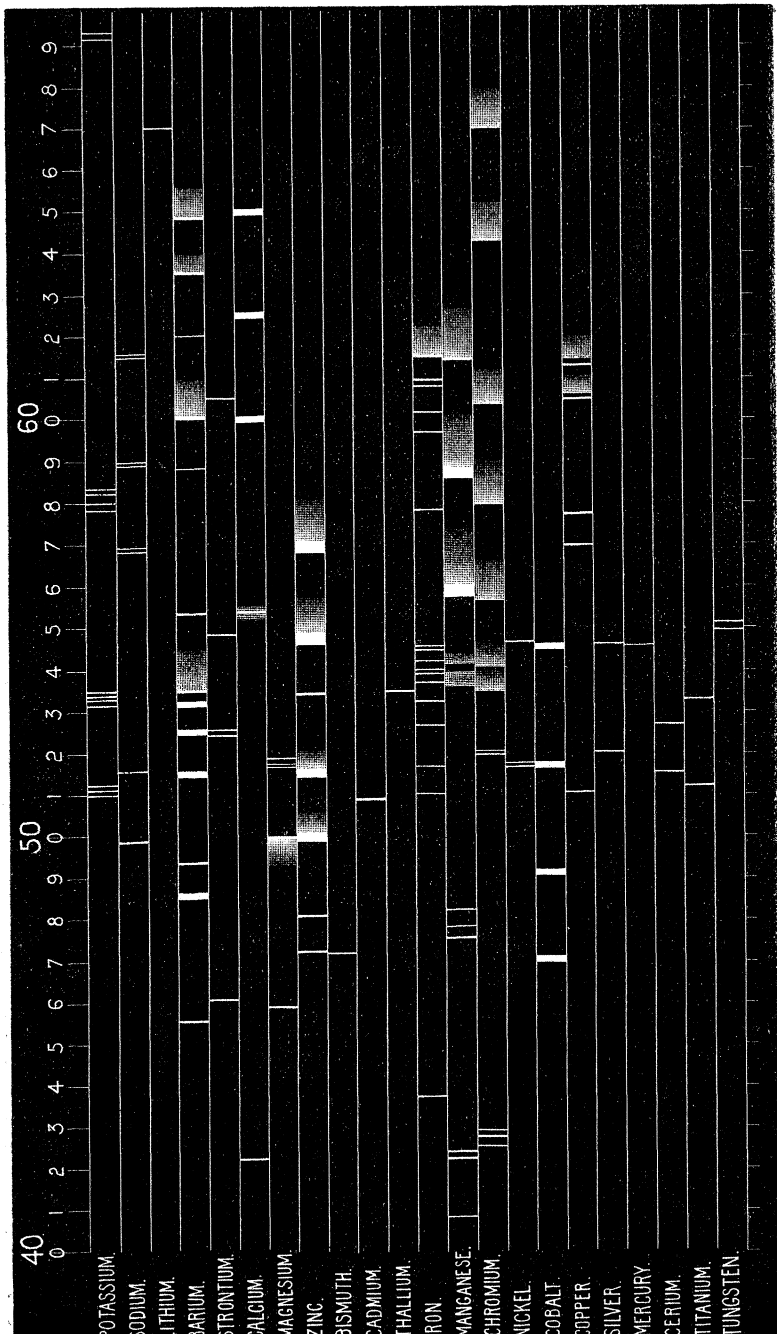
The following table shows the positions of the principal lines, bands, and flutings seen in the spectrum of each of the metals examined, arranged roughly in the order of their intensities.

It should here be stated that as some of the researches have had to

deal with feeble illumination small dispersion has been of necessity employed, and to make the observations along the several lines comparable a one-prism spectroscope has been so far used throughout. Hence the wave-lengths given are in all cases only approximate. With this proviso the lines observed have been as follows:—

Lines	In bunsen—						
	Mg	5183,	5172,	5167,	4586,	5201.	
	Na	5889,	5895.				
	Li	6705.					
	Tl	5349.					
	Sr	4607.					
	Ba	5534.					
	Ca	4226.					
	Mn	5395.					
	K	6950.					
	Bi	4722.					
	Seen on passing from the temperature of the bunsen to that of the oxy-coal-gas flame—						
	Fe	5268,	5327,	5371,	4383,	5790,	6024.
	Cu	5105,	5781,	5700.			
	Cr	5202,	5203,	5207,	5410.		
	Zn	4810,	4911.				
	Cd	5085.					
	Ni	5476.					
	Ti	5128,	5338.				
	W	5490,	5511.				
	Ag	5208,	5464.				
	Hg	5460.					
	Ce	5273,	5160.				
Bands	In bunsen—						
	Ca	5535,	6250,	6500,	6000.		
	Sr	6050.					
	Ba	5150,	5250,	5330,	4860.		
	Seen on passing from the temperature of the bunsen to that of the oxy-coal-gas flame—						
	Co	4710,	4920,	5170,	5460.		
Flutings	In bunsen—						
	Mg	5000.					
	Mn	5580,	5860,	6145,	5340.		
	Seen on passing from the temperature of the bunsen to that of the oxy-coal-gas flame—						
	Ba	6010,	6350,	6480.			
	Cr	5360,	5570,	5800,	6040.		
	Fe	6150.					
	Cu	6050,	6130.				
	Zn	5460,	5680,	4985,	5140,	5340.	

All the flutings, with the exception of magnesium, have their maxima towards the blue, and shade off towards the red end of the spectrum.



Map I.—Spectra of metals at the temperature of the oxy-coal-gas blowpipe.

C. *Experiments upon Mg at low Temperatures.*

I have again gone over the experiments already communicated to the Royal Society ('Roy. Soc. Proc.,' vol. 30, p. 27), and in addition have observed the spectrum of the metal burning in the centre of a large bunsen burner, in which case we get the line at 5201, and the fluting in the position of *b* without the fluting at 500. In the bunsen as ordinarily employed the fluting at 500 far eclipses the other parts of the spectrum in brilliancy, and at this temperature, as already observed by Messrs. Liveing and Dewar ('Roy. Soc. Proc.,' vol. 32, p. 202), the ultra-violet line visible is that at 373. Lecoq de Boisbaudran has observed the lines in the chloride at 4705 and 4483 ('Spectres Lumineux,' p. 85).

D. *Experiments upon the Glow of Na and Mg in Vacuum Tubes.*

A small piece of sodium, free from hydrocarbon, was placed in the lower limb of an end-on spectrum tube, and arrangements made for observing the spectrum of the gas evolved when the sodium was heated. Having first obtained as perfect a vacuum as possible, the sodium was gently heated, and the spectrum of the gas then gave nothing but the C and F lines of hydrogen. The pump being stopped and the sodium heated, a point was reached when C and F became very dim and were replaced by the structural spectrum of hydrogen.

In another experiment the sodium was replaced by a piece of magnesium along the end-on tube. The same process being gone through, similar phenomena were observed, but in the latter case there was a line at 500, in addition to the lines seen in the case of sodium.

The important point, then, is the existence of a line at 500 in the spectrum when magnesium is heated, and the absence of such a line in the gas evolved by sodium under the conditions stated.

E. *Experiments upon the Conditions under which the C and F Lines of Hydrogen disappear from the Spectrum.*

The association of the bright lines of hydrogen with nebulæ, many of the stars with bright lines, and the so-called new stars, points out at once that it is important to consider the various changes which hydrogen can undergo under various conditions of temperature and pressure. I pointed out many years ago that, when under certain conditions the spectrum of hydrogen is examined at the lowest possible temperature, the F line retains its brilliancy long after C disappears; and the fact that, after the chief lines of hydrogen have been made to disappear from the spectral tube, the spectrum which remains visible, and is sometimes very brightly visible, is also due to hydrogen, has always been a matter of thorough belief in my mind, although so

many observers, down even to M. Cornu not so very long ago, have been inclined to attribute it to the existence of "impurities."

I began to map the so-called structural spectrum at the College of Chemistry in 1869, but other matters supervened which prevented the accomplishment of this work. This, however, is a matter of small importance, because quite recently Dr. Hasselberg has communicated to the St. Petersburg Academy an admirable memoir on the subject, accompanied by a map ('Mémoires de l'Académie Impériale,' Series vii, vol. 30, No. 7, Hasselberg). The brightest portions of the structure-spectrum are shown in Map 2.

The most convenient way of obtaining a supply of hydrogen for investigations of this kind is to use a little sodium which has never been in contact with hydrocarbon, or a piece of magnesium wire; to place them in the low end of a glass tube, one part of which can be used as an end-on tube, and then, after getting a vacuum so perfect that the spark will not pass, to slightly heat the metal. After a time the spectrum of hydrogen, sometimes accompanied by the low-temperature flutings of carbon, begins to be visible alike from the sodium and the magnesium.

If the vacuum has been very perfect to start with, at first the bright lines C and F will be visible without any trace of structure, and the hydrogen will be of a magnificent red colour. If now the action of the pump be stopped, and the sodium be still more heated, a point will be reached at which the conductibility of the gas is at its maximum, and then, the jar not being in circuit, the structure-spectrum of the gas will be seen absolutely alone, without any trace of either C or F. The gradual disappearance of the F line is very striking, and when the bright line is out of the field the lines due to the structure seem to be enhanced in brilliancy.

The brightest part of the spectrum is then that near D; in the blue-green we have a line at 464 more refrangible than F, and then a double line at 4930 and 4935; other less refrangible lines are seen. These are phenomena seen associated with sodium, but if we use the hydrogen produced from a piece of magnesium wire or from a crystal of olivine, under the same circumstances we find that so far as the lines of hydrogen go the phenomenon remains the same, but that there is then visible in the spectrum a line at 500, which has been recorded in the spectrum of magnesium under other conditions, not only by myself but by Dr. Copeland.*

* "To this table must be added 500·6 mmm. as the wave-length of the first line in the great band of magnesium as determined by M. Lecoq de Boisbaudran from the spark spectrum of the chloride of that metal, which evidently agrees with the flame spectrum, in this region at least. It is worthy of note that this line almost absolutely coincides with the brightest line in the spectra of planetary nebulæ." (Dr. Copeland, 'Copernicus,' vol. 2, p. 109.)

F. *Experiments upon the Spectra of Meteorites at low Temperatures.*

All the later observations recorded have been made on undoubted meteorites, fragments of which have been in the kindest manner placed at my disposal.

I. *In the Oxyhydrogen Flame.*

The observations gave in all only about ten or a dozen lines belonging to the metals magnesium, iron, sodium, lithium, and potassium, and two flutings, one of manganese, and one of iron.

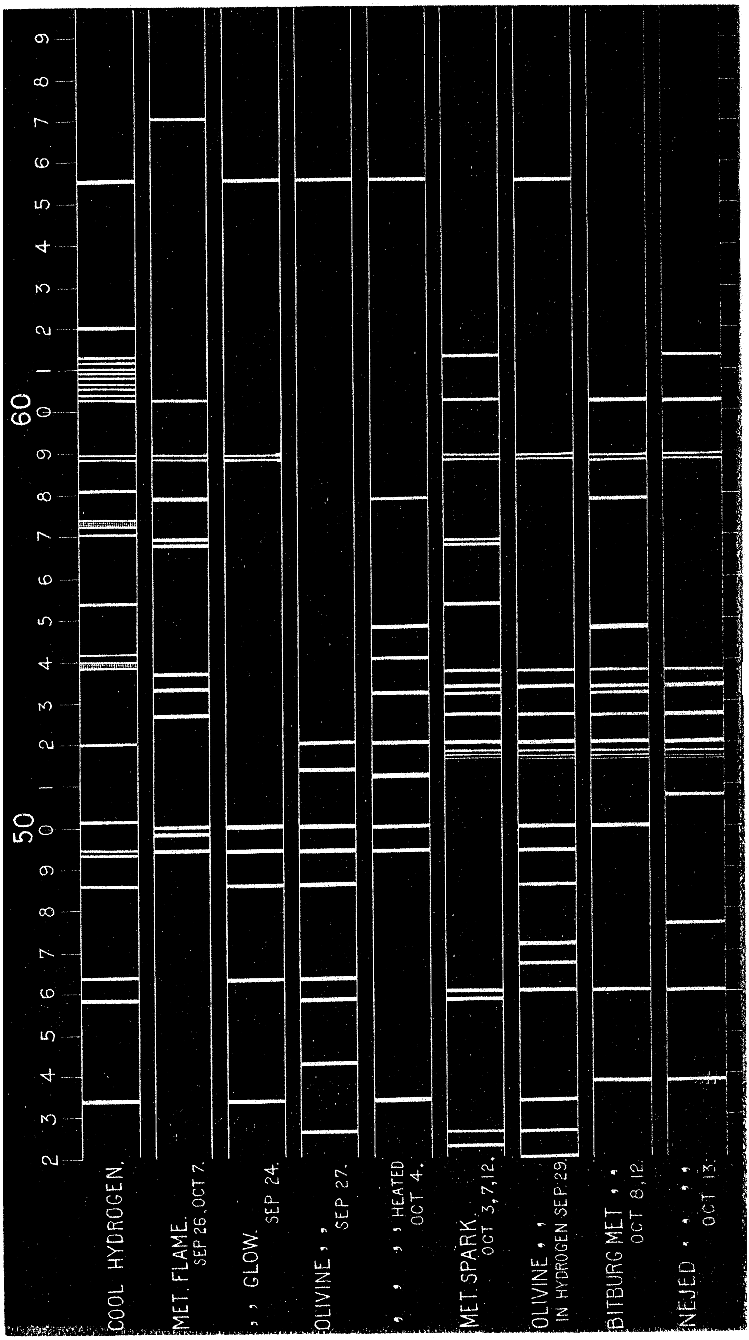
II. *With a Quantity Coil without Jar.*

The observations gave in all about twenty lines belonging to the metals magnesium, sodium, iron, strontium, barium, calcium, chromium, zinc, bismuth, and nickel, and four lines of unknown origin.

III. *When heated in a Vacuum Tube when a Current is passing along it.*

A small piece of iron meteorite was enclosed in the middle of a horizontal tube, so that the spark might be made to pass through the tube and over the meteorite. After complete exhaustion has been obtained, the first spectrum obtained when the tube, end on, is placed in front of the spectroscope, is a spectrum of hydrogen. The carbon flutings are only visible occasionally. If the meteorite then be very gently warmed by placing a bunsen burner at some distance below the tube, the glow over the meteorite is seen to change its colour, and the line at 500 is constantly, and another line at 495, apparently exactly in the position of the second line of the spectrum of the nebulæ, is occasionally, seen. This line is less refrangible than the structure line of hydrogen in this region, which occupies the same position as the barium line. This, however, if the heating is continued, especially in the case of stony meteorites, is soon succeeded by a much more brilliant green glow, in which magnesium *b* and many other lines appear, now accompanied by the carbon flutings. The observations made under all the above conditions are shown in Maps 2 and 2A.

In these observations if a line in the meteoric spectrum were coincident with a metallic line, with the dispersion employed, in the absence of the brightest line of that metal, the line was regarded as originating from some other substance. Thus a line was sometimes seen at 5480, apparently coincident, with the dispersion employed, with the green lines of Sr and Ni; sometimes the brightest line of Sr at 4607 was absent, and it was then fair to assume that the presence of 5480 was due to Ni, but in the presence of 4607 it might be due to Sr.


2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9
50
60
COOL HYDROGEN.
MET. FLAME. SEP 26, OCT 7.
" " GLOW. SEP 24.
OLIVINE " " SEP 27.
" " " " HEATED OCT 4.
MET. SPARK. OCT 3, 7, 12.
OLIVINE " " IN HYDROGEN SEP 29.
BITBURG MET " " OCT 8, 12.
NEJED " " " " OCT 13.

Map 2.

Map 2a.—Spectra of Olivine and Meteorites under various conditions.

Comparisons of the foregoing Observations among themselves, and with those made on various Orders of Celestial Bodies.

The discussions have taken, in the first instance, the form of comparisons of the different phenomena observed, and for this purpose all recorded observations of flutings and bright lines and dark lines in stars, comets, nebulæ, &c., have been carefully mapped in addition, all records having, when necessary, been brought to a common scale. Having these maps, I could then compare the totality of celestial observations with the laboratory work to which reference has already been made.

The following are among the comparisons already dealt with :—

I. The spectra of meteorites observed under the various conditions, chiefly considering magnesium, iron, and manganese, with the bright lines observed at low temperatures.

The main conclusions are :—

(1.) That only the lowest temperature lines of Mg, Na, Fe, Cr, Mn, Sr, Ca, Ba, K, Zn, Bi, and Ni are seen in the meteorites under the various conditions. They are not all seen in one meteorite or under one particular condition; the details of individual observations are fully recorded in Maps 2 and 2A.

(2.) That in the case of Mg the line most frequently seen is the remnant of the fluting at 500, while in a photograph the main ultra-violet line recorded is the one at 373, previously recorded under these conditions by Messrs. Liveing and Dewar. In the quantity spark other lines are seen, notably b_1, b_2, b_4, and 5201. The line at 500 was considerably brightened when the number of cells was reduced, thus showing it to be due to some molecule which can exist best at a low temperature.

(3.) That in the case of Mn the only line visible at the temperature of the Bunsen burner, 5395, is the only line seen in the meteorites.

(4.) That the lines of iron seen in the meteorites are those which are brightest when wire gauze is burned in the flame. The chief of these are 5268, 4383, 5790, and 6024; it is possible, however, that the two latter are due to some substance, not iron, common to the gauze and the meteorites.

II. The spectra of meteorites generally, with the bright lines and flutings seen in luminous meteors, comets, and some "stars."

α. Luminous Meteors.

With regard to the records of luminous meteors, it may be remarked that the observations, so far as they have gone, have given decided indications of magnesium, sodium, lithium, potassium, and of the carbon flutings seen in comets. The following quotations from

Konkoly and Professor Herschel are among the authorities which may be cited for the above statement.

"On August 12, 13, and 14 I observed a number of meteors with the spectroscope; amongst others, on the 12th, a yellow fireball with a fine train, which came directly from the Perseid radiant. In the head of this meteor the lines of lithium were clearly seen by the side of the sodium line. On August 13, at 10h. 46m. 10s., I observed in the north-east a magnificent fireball of emerald-green colour, as bright as Jupiter, with a very slow motion. The nucleus at the first moment only showed a very bright continuous spectrum with the sodium line; but a second after I perceived the magnesium line, and I think I am not mistaken in saying those of copper also. Besides that, the spectrum showed two very faint red lines."*

"A few of the green 'Leonid' streaks were noticed in November (1866) to be, to all appearances, monochromatic, or quite undispersed by vision through the refracting prisms; from which we may at least very probably infer (by later discoveries with the meteor-spectroscope) that the prominent green line of magnesium forms the principal constituent element of their greenish light."†

Again, later on in the same letter, Professor Herschel mentions Konkoly's observations of the bright *b* line of magnesium, in addition to the yellow sodium line in a meteor on July 26, 1873.

I again quote from Professor Herschel:—

"On the morning of October 13 in the same year, Herr von Konkoly again observed with Browning's meteor-spectroscope the long-enduring streak of a large fireball, which was visible to the north-east of O'Gyalla. It exhibited the yellow sodium line and the green line of magnesium very finely, besides other spectral lines in the red and green. Examining these latter lines closely with a star-spectroscope attached to an equatorial telescope, Herr von Konkoly succeeded in identifying them by direct comparison with the lines in an electric Geissler-tube of marsh-gas. They were visible in the star-spectroscope for eleven minutes, after which the sodium and magnesium lines still continued to be very brightly observable through the meteor-spectroscope."‡

The green line "*b*" of magnesium occurring as a bright line in luminous meteors indicates that their temperature when passing through our atmosphere is higher than that of the bunsen, and we may add of comets as generally observed, although some exhibit the *b* lines of magnesium and those of iron when at perihelion, as shown later on.

The two lines which Konkoly supposes are probably due to copper

* Konkoly, 'Observatory,' vol. 3, p. 157.

† Herschel, letter to 'Nature,' vol. 24, p. 507.

‡ *Ibid.*

will, I expect, be found to be iron lines when other observations are made of the spectra of meteors.

The main conclusions from this comparison are then: (1) that the temperature of luminous meteors is higher than that of the Bunsen flame; (2) that the meteorites which produce the phenomena we are now discussing are hotter than those in the experimental glow taken generally; and (3) that in both cases flutings of carbon may be seen.

β. *Comets.*

When the meteorites are *strongly* heated in a glow-tube, the whole tube when the electric current is passing gives us the spectrum of carbon.

When a meteor-swarm approaches the sun, the whole region of space occupied by the meteorites, estimated by Professor Newton in the case of Biela's comet to have been thirty miles apart, gives us the same spectrum, and further it is given by at all events part of the tail, which in the comet of 1680 was calculated to be 60,000,000 miles in length. The illumination therefore must be electrical, and possibly connected with the electric repulsion of the vapours away from the sun; hence it is not dependent wholly upon collisions.

Passing now from the flutings seen in cometary spectra, it is found that most of the lines which have been observed at perihelion are coincident with lines seen in experiments with meteorites, while the low temperature lines of Mg are absent. In the great comet of 1882, to which particular attention has been given on account of the complete record of its spectrum by Copeland,* the lines recorded were the D lines of sodium, the low temperature iron lines at 5268, 5327, 5371, 5790, and 6024, the line seen in the manganese spectrum at the temperature of the bunsen burner at 5395, and a line near *b* which might be due to magnesium, or to a remnant of the carbon fluting. In addition to these there was a line at 5475, probably due to nickel, the absence of the blue strontium line indicating that it is not likely to be the green line of strontium. There were also four other lines less refrangible than D, the origin of which has not yet been determined. As the comet got further from perihelion the lines gradually died out, those which remained longest being the iron line at 5268 and the line near *b*. The absence of D before the disappearance of all the lines is probably to be accounted for partly by the greater brightness of the continuous spectrum in that region.

In the comets of 1866-67, when seen away from the sun, the only line seen was the one at 500.†

* 'Copernicus,' vol. 2, p. 234.

† "In January, 1866, I communicated to the Royal Society the result of an examination of a small comet visible in the beginning of that year ('Roy. Soc. Proc.,' vol. 15, p. 5). I examined the spectrum of another small and faint comet in May,

It is fair to myself to say that I was not aware of these observations when I began to write this paper. The fact of the line at 500 remaining alone in Nova Cygni made it clear that if my views were correct, the same thing should happen with comets. It now turns out that the crucial observation which I intended to make was made twenty years ago.

In Comets *b*, 1881, and *c*, 1882, the only lines recorded were magnesium *b*; but, as before, the apparent absence of other lines might be due to continuous spectrum.

Of the five bands shown in Huggins's photograph of the spectrum of Comet Wells, taken with a wide slit, no less than three agree fairly in position with three lines seen in the spectra of meteorites. The wave-lengths of these are 4253, 4412, and 4769, and it is interesting to note that, so far, the origin of these lines is undetermined. The two remaining bands are at wave-lengths 4507 and 4634.

It is seen, then, that the spectra of comets—when their internal motions are relatively either slow or fast, and when therefore the number of collisions, and with it the heat of the stones in collision, will vary extremely—resemble the spectra of meteorites seen in glow tubes.

γ. "*Stars*" *with Flutings which have been observed in the Laboratory and in Luminous Meteors and Comets.*

The most prominent bright flutings of carbon are not only observed in luminous meteors and comets, but in stars of Class III*a*, and in some "Novas," notably Nova Orionis. So far, then, these bodies may in a certain measure be classed with luminous meteors and comets. But there is an important difference in the phenomena, for we have absorption as well as radiation. The discussion shows that the dark (or absorbing) flutings in these bodies are partly due to the absorption of light by the most prominent flutings of Mn and Zn, seen at low temperatures. This inquiry is being continued.

We have, then, in these bodies a spectrum integrating the *radiation* of carbon and the *absorption* of Mn and Zn vapour.

The law of parsimony compels us to ascribe the bright fluting of carbon in these stars to the same cause as that at work in comets, where we know it is produced by the vapours between the individual meteorites or repelled from them.

Hence we are led to conclude that the absorption phenomena are

1867. The spectra of these objects, as far as their feeble light permitted them to be observed, appeared to be very similar. In the case of each of these comets the spectrum of the minute nucleus appeared to consist of a bright line between *b* and F, about the position of the double line of the spectrum of nitrogen, while the nebulosity surrounding the nucleus and forming the coma gave a spectrum which was apparently continuous" (Huggins, 'Roy. Soc. Proc.,' vol. 16, p. 387).

produced by the incandescent vapour surrounding the individual meteorites which have been rendered intensely hot by collisions.

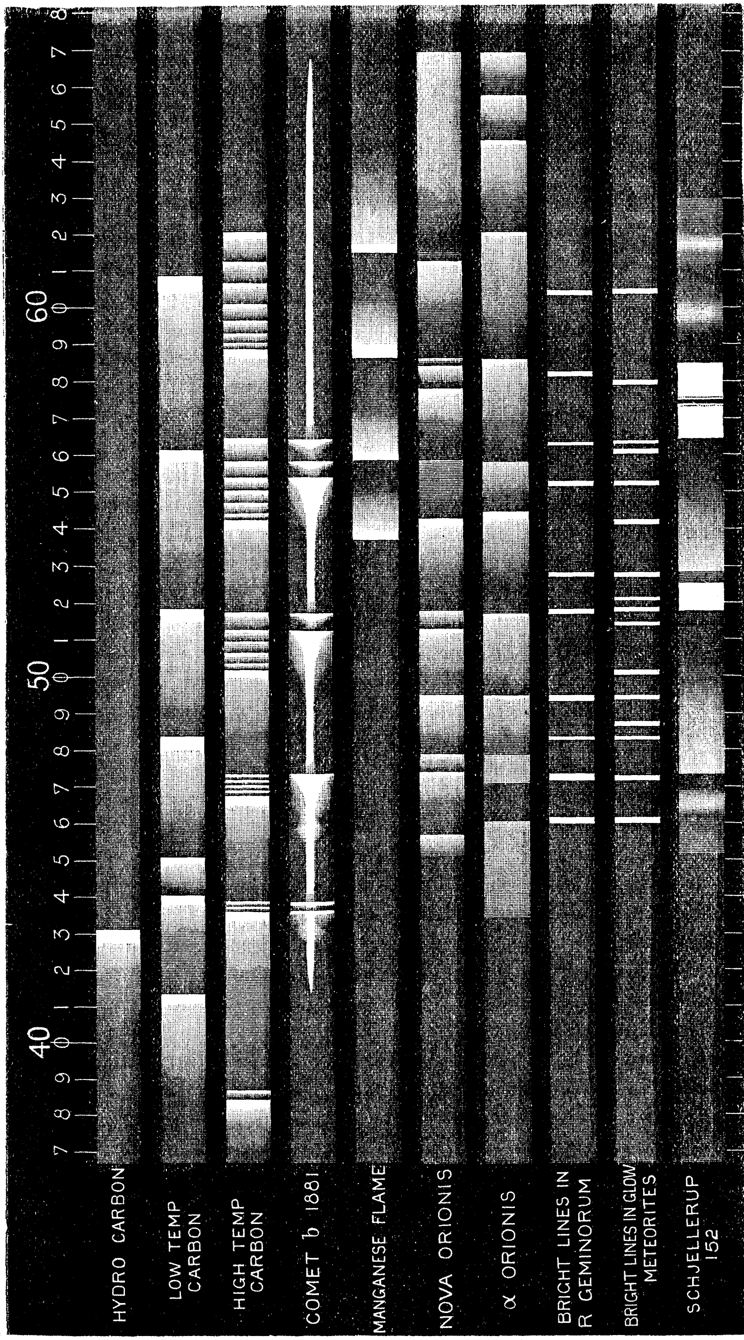
These stars, therefore, are not masses of vapour like our sun, but clouds of incandescent stones.

We have here probably the first stage of meteoritic condensation.

The Cases of Nova Orionis and R. Geminorum.

The stars with bright carbon flutings, the same as those seen in comets, are not limited to first-magnitude stars, such as α Orionis, but include at least one new star, Nova Orionis. Because the latter star lasted but a short time we might expect the phenomena presented to be different from those found in the first-magnitude star, which is a variable, like others with similar composite spectra. Practically there is a little difference, for in α Orionis, α Herculis, and others of that type, we find well-marked dark absorption flutings of manganese, as well as line-absorption of sodium and magnesium. The manganese absorptions agree with some of the Mn flutings seen in the Bessemer flame by Marshall Watts ('Phil. Mag.,' February, 1873). The absorptions are not so well developed in the Nova, for the reason, perhaps, that condensation due to gravity had not taken place to such a great extent, so that the heat of the stones themselves was not so great, and further because the local absorption around each meteorite would be cloaked by the bright radiation of the interspaces, which gives, as in comets, the maximum intensity to the bright fluting, wave-length 517. In R. Geminorum the demonstration of the same meteoric constitution, but without the strong absorption, is given by the fact that in that star so much of the light proceeds from the vapour produced by the meteorites, and from the carbon in the interspaces, that the carbon flutings and the bright lines of barium and strontium, and other substances present in meteorites, are visible at the same time, exactly as they are seen in the glow over a meteorite in an experimental tube, in which, as the pressure is reduced, the edges alone of the carbon flutings are visible, and put on the appearance of bright lines, almost exactly resembling the bright lines of the heated meteorites.

The spectra of these two stars I give on a map (Map 3) side by side with the bright flutings of carbon and the bright flutings of manganese with a view of showing that, both in the temporary Nova and the first magnitude star in the same constellation, many of the phenomena are the same and are therefore probably produced by the same cause. Some time after Dr. Copeland's original observations of this star were published, it was pointed out by Dunér, Vogel, and others, that some of the bright parts of the spectrum observed by him were really coincident with the bright parts of the spectrum of α Orionis; this, of course, is beyond question. But in addition to



Map 3.—Comparison of flutings seen in the spectra of "stars" and comets, with flutings of carbon, manganese, and zinc, and in the case of R. Geminorum lines with remnants of flutings and lines seen in a meteorite glow. (The Zn fluting is at λ 544 in α Orionis.)

these bright spaces Dr. Copeland gives some bright regions which, I think, have not been touched by the arguments of Vogel and Dunér above referred to. It will be observed that in the case of R. Geminorum, given on the same map as Nova and α Orionis, the bright lines correspond almost exactly with the bright spaces shown in the above-named stars and certain lines seen in meteorites—that is to say, a meteorite glow, when the carbon spectrum is bright, gives us all the lines recorded in the spectrum of the star, showing that some of the lines correspond with the brightest flutings of carbon.

There can be no question, I think, that in R Geminorum we have another stage, doubtless a prior stage, of the life-history not only of the Nova, but of α Orionis itself.

III. The spectra of meteorites glowing in tubes with the bright lines observed in celestial bodies—

(α) Comparison with the lines seen in nebulæ when C and F (bright) are either present or absent.

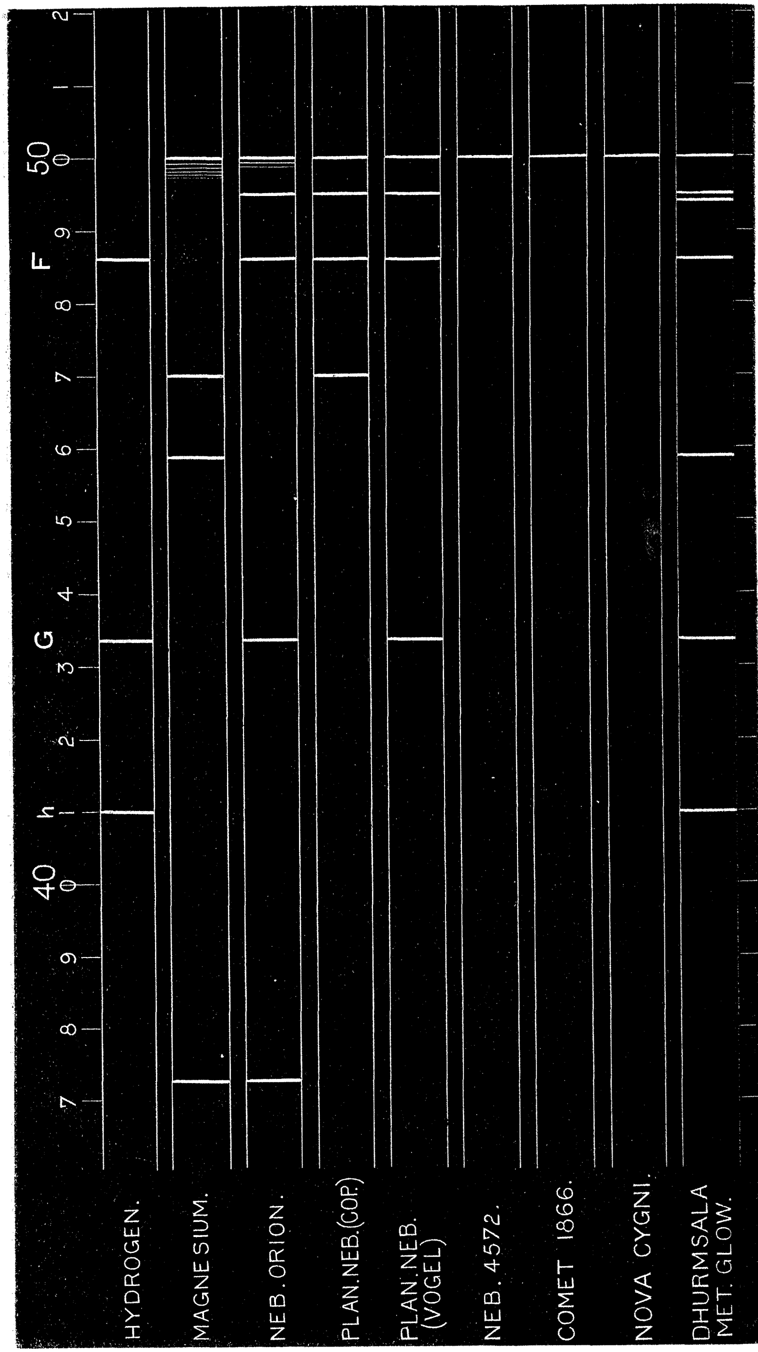
(β) Comparison with bright lines (not associated with flutings) seen in stars.

α. "*Nebulæ.*"

Only seven lines in all have been recorded up to the present in the spectra of nebulæ, three of which coincide with lines in the spectrum of hydrogen and three correspond to lines in magnesium. The magnesium lines represented are the ultra-violet low-temperature line at 373, the line at 470, and the remnant of the magnesium fluting at 500, the brightest part of the spectrum at the temperature of the bunsen burner. The hydrogen lines are *h*, F, and Hγ (434). Sometimes the 500 line is seen alone, but it is generally associated with F and a line at 495. The remaining lines do not all appear in one nebula, but are associated one by one with the other three lines. The lines at 500 and 495 and F have been seen in the glow of the Dhurmsala meteorite when heated, but the origin of 495 has not yet been determined.

The result of this comparison then is that the nebula spectrum is as closely associated with a meteorite glowing very gently in a very tenuous atmosphere given off by itself as is the spectrum of a comet near the sun with a meteorite glowing in a denser one also given off by itself when more highly heated.

Further, it has been seen that the nebula spectrum was exactly reproduced in the comets of 1866 and 1867, when away from the sun. As the collision of meteorites is accepted for the explanation of the phenomena in one case, it must, *faute de mieux*, be accepted for the other. The well-known constituents of meteorites, especially olivine,



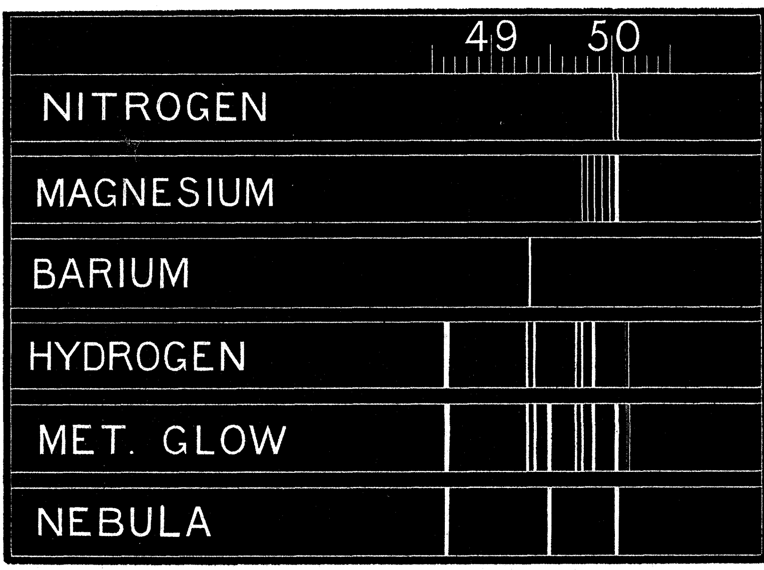
Map 4.—Spectra of nebulæ compared with the spectra of hydrogen, cool Mg, and meteorite glow.

fully explain all the spectroscopic phenomena presented by luminous meteors, comets, and nebulæ.

I published many years ago an experiment in which I had found that the gases evolved from meteorites under some conditions gave us the spectrum of hydrogen and under others the spectrum of carbon; but in the globes I then used I was not enabled to study the spectrum of the glow itself.

I should add that the line at 495 makes its appearance much more rarely than the one at 500, in meteorite glows.

Map 5 shows the positions of three of the nebula lines as compared with well-known lines.



Map 5.—Diagram showing the positions of the nebula lines as compared with lines of N, Mg, Ba, H, and meteorite glow.

β. "Stars" with bright Lines.

On reference to the map which I exhibit to the Society, though they and the discussion of them are yet incomplete, it will be seen that the principal lines which are seen bright in star spectra are, if we make due allowance for the discrepancies likely to occur in observations attended with great difficulties, lines which either have been observed in the vapours and gases given off by meteorites in vacuum-tubes, or which we might expect to see in a combined series of observations on meteorites having different chemical constituents. Among these lines are Hα, Hβ, Hγ, Hδ, 464, 540, 570, 580, 587; in

one case (1st Cygnus) there are lines at 5065 and 5268, the latter due to iron. The difficulties attending this part of the inquiry are referred to subsequently, and it must be understood that in the absence of a detailed discussion, especially of the spectra of the "Novas," which I have not yet completed, the opinions I express in the next part of this preliminary notice with regard to bright-line stars must be regarded rather as suggestions than as final conclusions.

Discussion of the Maps showing the bright Lines visible in Stars and Nebulæ.

It results from the discussion of the bright lines seen, whether associated with the bright lines C and F of hydrogen or not, that, while on the one hand we have a class of bodies—the nebulæ—which give us the lines visible at the lowest temperature of chemical elements known to exist in meteorites, we have in the other class—the "stars" with bright lines—those lines visible at somewhat higher temperatures in meteorites. In the stars with bright lines the two most important lines, which have been separately mapped by Vogel,* occur at 540 and 582. The mean readings of all the observations give the positions of these lines as 540 and 580. In an experiment on the glow of a meteorite rich in manganese, the line of Mn at 5395, easily seen at the temperature of the bunsen, is distinctly seen in addition to the structure-spectrum of hydrogen. There is reasonable ground therefore for supposing that the line, this only one of the iron-group of metals visible at the temperature of the bunsen, may be the origin of one of the two lines seen alone in the spectrum of these "stars." It will be seen that in the map it has been easy to arrange all the bright lines hitherto seen in stars into one order, in which we begin with this line of manganese, and a line of iron seen at the temperature of the oxy-coal-gas flame, the wave-length of which is 579. As other lines indicating other substances are added to these fundamental ones, we pass from those stars in which C and F are not visible to those in which they make their appearance. Here, however, it is necessary to move with caution, because it may be that we are in presence of some of the lines visible in the structure-spectrum of hydrogen. The chief lines of hydrogen, as seen in the end-on tube when the conditions are such that C and F are not visible, have been already stated. Some of the lines observed in these stars, even the one at 540, have been found to be very nearly coincident with bright lines seen in the structure-spectrum, as well as with lines seen in the spectra of meteorites.

The suggestion, therefore, that some of the lines seen in bright-line stars are lines of cool hydrogen must be noted, although there are grounds for rejecting it, as will shortly appear. One objection is

* 'Publicationen des Astrophys. Observatoriums zu Potsdam,' vol. 4, No. 14.

that strong lines of the H structure at 607—610 and 574 have not been recorded in star spectra with those at 540 and 580.

In the nebulæ we deal chiefly with lines seen in the spectrum of magnesium at the lowest temperature; and these, as far as observations go, have not yet been associated with the lines at 540 and 580 to which reference has just been made, although they may or may not be associated with the bright lines C and F of hydrogen. In the nebulæ, however, no lines coincident with the lines of cool hydrogen have been observed. It will be seen, therefore, that we have here again strong grounds for rejecting the view that the lines seen in "stars" at 540 and 580 are due to cool H, for since hydrogen is common to both nebulæ and stars, there is no reason why structure-lines should occur in "stars" any more than in nebulæ.

Another ground for rejecting cool hydrogen as the origin of any of the lines in "stars" is that the structure-spectrum of hydrogen is only seen in confined glows, which is just the condition which cannot occur in space.

At the same time, the apparent coincidences of so many meteorite lines with structure-lines of hydrogen greatly increases the difficulties of laboratory work; in fact, the structure spectrum of hydrogen is to observations of meteorite glows in the laboratory what continuous spectrum is to observations of bright lines in stars.

If it be agreed that we are not dealing with cool hydrogen, then it will follow that the only difference between celestial bodies with bright lines in their spectra comes from no difference of origin or chemical constitution, but from a difference of temperature.

At one point in these researches I was under the impression that the differences in the systems of bright lines seen in the nebulæ and the bright-line stars might arise from a preponderance of irons or stones in the swarms. But I was led to abandon this idea, not only by the observation of the meteoritic glows, but by the consideration that even telescopically the "stars" in question are more condensed than the nebulæ.

The spectrum of the nebulæ, except in some cases, is associated with a certain amount of continuous spectrum, and meteorites glowing at a low temperature would be competent to give the continuous spectrum with its highest intensity in the yellow part of the spectrum; so that in this way we should understand that lines due to any gas or vapour in that part would be very much more likely to escape record than those in the part of the spectrum which the continuous spectrum hardly reaches. The general absence, however, of bright lines of metallic vapours, except 495 and 500, and of the bright lines of hydrogen, evidently justifies the conclusion that we are here in presence of those bodies in celestial space, connected with which the temperature and the electrical excitation are at the minimum, and it

is very remarkable how the lines seen in a Geissler tube under the conditions stated, when either magnesium, or olivine, or other meteoric constituents are made to glow, should appear, one may almost say, indiscriminately among the orders of bodies in the heavens which up to the present time have been regarded as so utterly different in plan and structure as stars and nebulæ.

The records of purely continuous spectra in the case of many nebulæ, as for example the Great Nebula in Andromeda, is in all probability an indication of our inability to observe them properly. For a nebula to give a perfectly continuous spectrum, it is evident that the component meteorites must be incandescent, but still at a lower temperature than that required to give bright lines. Now the Mg line 500 is seen in some of the faintest nebulæ where there is little or no continuous spectrum, and it therefore seems likely that these are at a lower temperature than the nebulæ said to give perfectly continuous spectra. This being so, it is difficult to believe that other lines, which require a somewhat higher temperature for their existence than the line at 500, do not become visible at this increased temperature.

There can be little doubt that when our instrumental appliances and observing conditions become more perfect, it will be found that the so-called continuous spectra are really discontinuous. There is, indeed, an element of doubt as regards some of the existing observations; thus, the spectrum of the companion to the Great Nebula in Andromeda appears to end abruptly in the orange, and throughout its length is not uniform, but is evidently crossed by lines of absorption, or by bright lines.*

Again, the Great Nebula in Andromeda is generally regarded as having a continuous spectrum pure and simple, but an observer at Yale College (name not stated), has observed three bright lines in its spectrum ('Observatory,' vol. 8, p. 385). The lines are the F line of hydrogen, and two other lines at wave-lengths 5312·5 and 5594·0. The latter two lines are mentioned by the same observer as bright lines in γ Cassiopeiæ and β Lyræ, and are recorded by Sherman ('Astr. Nachr.' No. 2691) as bright lines in these stars and in Nova Andromedæ. No other observations with which I am acquainted give these two lines in γ Cassiopeiæ and β Lyræ, but Maunder ('Monthly Notices,' vol. 46, p. 20) gives them as two of the lines seen in Nova Andromedæ. It is possible, therefore, that the two lines in question, in the Yale College observations, had their origin in Nova Andromedæ; at all events there is no evidence to show that they are visible in the Great Nebula of Andromeda under normal conditions.

It is not impossible that the lines at 540 and 580 may be eventually traced in some of the brightest nebulæ, since these are apparently the lines next in order, as regards temperature, to the Mg line 500.

* Huggins, 'Phil. Trans.,' vol. 154, p. 441.

It is right that I should here point out that some observers of bright lines in these so-called stars have recorded a line in the yellow which they affirm to be in the position of D_3; while on the other hand, in my experiments on meteorites, whether in the glow or in the air, I have seen no line occupying this position.

I trust that some observer with greater optical means will think it worth his time to make a special inquiry on this point. The arguments against this line indicating the spectrum of the so-called helium are absolutely overwhelming. The helium line so far, has only been seen in the very hottest part of the sun which we can get at. It is there associated with *b*, and with lines of iron which require the largest coil and the largest jar to bring them out, whereas it is stated to have been observed in stars, where the absence of iron lines and of *b* shows that the temperature is very low. Further no trace of it was seen in Nova Cygni, and it has even been recorded in a spectrum in which C was absent, and once as the edge of a fluting.*

It is even possible that the line in question merely occupies the position of D_3 by reason of the displacement of D by motion of the "stars" in the line of sight. On this point no information is at hand regarding any reference spectrum employed. If, however, it should eventually be established that the line is really D_3, which probably represents a fine form of hydrogen, it can only be suggested that the degree of fineness which is brought about by temperature in the case of the sun, is brought about in the spaces between meteorites by extreme tenuity.

The Case of Nova Cygni.

The case of Nova Cygni is being discussed, and it appears likely that this "star" passed through all the stages of temperature represented by "stars" with bright lines, comets, and nebulæ. In the initial stage, the principal lines recorded were those of hydrogen, cool magnesium, and sodium. At a later date, in addition to these, lines apparently indicating hotter magnesium and carbon were observed. On the date of its highest temperature (December 8, 1876) the lines observed by Vogel indicate H, Na, Mg, C, Fe, Mn, and Ba, the "star" having then, it would appear from the discussion so far as it has yet gone, approached the condition of the great comet of 1882 at perihelion. The Fe, Ba, C, and Na gradually disappeared, then the hydrogen followed, and the last stage of all was that in which Mg (500) appeared alone, as in the comets of 1866–67 and in nebulæ. The complete discussion, however, must be reserved for a future communication. It is sufficient to say here that it is very

* ". . . . The spectrum is very bright: two strong bands are seen in the red, then the D line, followed by a bright line (D_3), as the edge of a band . . . . (Konkoly, "Neuer Stern bei χ^1 Orionis," 'Astr. Nachr.,' 2712).

probable that all the spectroscopic phenomena of Nova Cygni will admit of explanation on the supposition that it was produced by the collision of two swarms of meteorites. The outliers were first engaged, and at the maximum the denser parts of the swarm.

Difficulties connected with the Discussion.

An inspection of the maps, on which are shown all the observations already made upon bright lines recorded in the spectra of celestial bodies, will indicate at first sight an apparent variation of the positions of the lines greater than might have been expected. This, however, I think will vanish on the consideration of the whole question; and for my part certainly all the examinations which I have been able to make have led me to the conclusion that the various observations have been far better than it was almost possible to hope for when the great difficulties of the observations themselves are considered.

When it is remembered that, in order to get a determination of the position of a bright line, comparison-spectra and prisms are needed, and that, from mechanical considerations alone, the application of these aids to research is very frequently attended with difficulties and uncertainties; and further, when we consider that many of the observations have been necessarily made without these aids; the striking coincidences on the maps become of very much greater importance than the slight variations seen between the positions of the same line recorded by different observers in the same star.

It will be observed, too, that the information in some cases is fuller in the blue part of the spectrum. Here again a reference to what the maps are really intended to show is necessary. The maps do not show the complete spectrum observed, but only the bright lines recorded in it. The actual observations have really consisted in picking out these bright lines from the background of continuous spectrum, whether in stars, nebulæ, or comets; and, as the continuous spectrum will be generally brightest in the yellow and green, so in this part of the spectrum we must expect, first of all, to get the least information, and then, when the information is obtained, to get the greatest uncertainty, on account of the difficulty brought about by the greater luminosity of the background on which the line appears.

The discussion by Hasselberg and others of the various observations of comets which have been made from time to time indicates that under certain circumstances, where men of the highest skill and with the greatest care have determined the wave-lengths of the carbon bands, discrepancies exist too great to admit of their being attributed to errors inherent in this branch of observation.

If for a moment we consider alone the two bright flutings visible in the spectrum of carbon, one with its bright edge just more refrangi-

ble than b_4—this is the high-temperature spectrum—and the other—the low-temperature spectrum—with a fluting just less refrangible than b_1, it is at once suggested that sudden changes in comets may very likely be accompanied by a transition from one condition of carbon vapour to the other, so that on this account apparent discrepancies in the measurements of the same comet at different times may present real facts. Then again we have the motion of the swarm along its orbit, which in some cases we know is comparable to the velocity of light, so that variations of wave-length are produced as indicated in comet 1882. We also have the possibility that the velocity of the vapours in the jets, and that due to the electric repulsion—which, according to Zöllner's view, is the origin of comets' tails—may also produce changes of refrangibility.

Although as a rule the bright fluting seen in comets appears to be that due to high temperature, this is apparently not always the case. In the experiments on the glow of magnesium wire, the flutings of carbon have always been seen, and when the vacuum is approached the flutings have been those of the low-temperature spectrum. When the glow of the metal is seen under certain conditions, mixed with carbon vapour, b_1 and b_2 are seen as bright dots or short lines inside the carbon fluting, exactly as they were observed, probably, by Huggins in Brorsen's comet ('Roy. Soc. Proc.,' vol. 16, p. 386).

Authorities used in the Maps.

The map showing the bright lines in *Stars* is based upon the following authorities :—

3rd Cygnus, B.D. +36°, No. 3956, R.A. 20 h. 10 m. 6 s., Decl. +36° 18′.
    Vogel.—'Publicationen des Astrophysikalischen Observatoriums zu Potsdam,' vol. 4, No. 14, p. 19.

2nd Cygnus, B.D. +35°, No. 4013, R.A. 20 h. 7 m. 26 s., Decl. +35° 50·8′.
    Vogel.—'Publicationen des Astrophysikalischen Observatoriums zu Potsdam,' vol. 4, No. 14, p. 19.
    Wolf and Rayet.—'Comptes Rendus,' vol. 65 (1867), p. 292. The wave-lengths were obtained from a curve based on the measurements given.

Argelander-Oeltzen 17681, R.A. 18 h. 1 m. 21 s., Decl. −21° 16·2′.
    Vogel.—'Publicationen des Astrophysikalischen Observatoriums zu Potsdam,' vol. 4, No. 14, p. 15.
    Pickering.—'Astronomische Nachrichten,' No. 2376.
    Pickering.—'Observatory,' vol. 4, p. 82.

γ Argus, R.A. 8 h. 5 m. 56 s., Decl. −46° 59·5′.
    Copeland.—'Copernicus,' vol. 3, p. 205.
    Ellery.—'Observatory,' vol. 2, p. 418.

Stone 9168 (star in Scorpio), R.A. 16 h. 46 m. 15 s., Decl. −41° 37·6′.
    Copeland.—'Copernicus,' vol. 3, p. 205.

1st Argus, R.A. 8 h. 51 m. 1 s., Decl. −47° 8′.
    Copeland.—'Copernicus,' vol. 3, p. 206.

2nd Argus, R.A. 10 h. 36 m. 54 s., Decl. −58° 8′.
    Copeland.—'Copernicus,' vol. 3, p. 206.

Gould 15305 (Argo), R.A. 11 h. 5 m. 19 s., Decl. $-60°\ 21'$.
Copeland.—'Copernicus,' vol. 3, p. 206.
Star in Centaurus, R.A. 13 h. 10 m. 37 s., Decl. $-57°\ 31'$.
Copeland.—'Copernicus,' vol. 3, p. 206.
Star in Cygnus, B.D. $+37°$ No. 3821, R.A. 20 h. 7 m. 48 s., Decl. $+38°\ 0{\cdot}1'$.
Copeland.—'Monthly Notices of the Royal Astronomical Society,' London, vol. 45, p. 90.
Lalande 13412, R.A. 6 h. 49 m. 15 s., Decl. $-23°\ 46{\cdot}8'$.
Vogel.—'Publicationen des Astrophysikalischen Observatoriums zu Potsdam,' vol. 4, No. 14, p. 17.
Pickering.—'Astronomische Nachrichten,' No. 2376.
1st Cygnus, B.D. $+35°$ No. 4001, R.A. 20 h. 5 m. 48 s., Decl. $+35°\ 49{\cdot}7'$.
Vogel.—'Publicationen des Astrophysikalischen Observatoriums zu Potsdam,' vol. 4, No. 14, p. 17.
γ Cassiopeiæ, R.A. 0 h. 50 m. 4 s., Decl. $+60°\ 7{\cdot}2'$.
Vogel.—'Publicationen des Astrophysikalischen Observatoriums zu Potsdam,' vol. 4, No. 14, p. 15.
Vogel.—'Beobachtungen zu Bothkamp,' Heft 2, p. 29.
Gothard.—'Astronomische Nachrichten,' No. 2581.
Konkoly.—Quoted by Gothard in 'Astronomische Nachrichten,' No. 2581. 'Observatory,' vol. 6, p. 332.
β Lyræ, R.A. 18 h. 45 m. 55 s., Decl. $+33°\ 13{\cdot}9'$.
Vogel.—'Publicationen des Astrophysikalischen Observatoriums zu Potsdam,' vol. 4, No. 14, p. 15.
Vogel.—'Beobachtungen zu Bothkamp,' Heft 1, p. 33.
Gothard.—'Astronomische Nachrichten,' No. 2581.

The map showing the bright lines in *Nebulæ* is based upon the following authorities :—

Nebula in Orion.
Huggins.—'Roy. Soc. Proc.,' vol. 14, p. 39.
Planetary Nebula, R.A. 21 h. 22 m., Decl. $+47°\ 22'$.
Copeland.—'Copernicus,' vol. 1, p. 2.
Planetary Nebula.
Vogel.—'Monatsberichte der Akademie der Wissenchaften zu Berlin,' April, 1878, p. 303.
No. 4572, 2075 h., 16 H. 4, R.A. 20 h. 16 m. 7·9 s., N.P.D. $74°\ 20'\ 19{\cdot}3''$.
Huggins.—'Philosophical Transactions,' vol. 154, p. 385.
Comet, 1886.
Huggins.—'Roy. Soc. Proc.,' vol. 15, p. 5.
Nova Cygni.
Lord Lindsay and Dr. Copeland.—'Copernicus,' vol. 2, p. 109.

The map showing the coincidence of flutings of carbon, manganese, and zinc, with bright lines and flutings in stars and comets, and in a meteorite glow, is based upon the following authorities :—

Hydrocarbon
Low temperature carbon } Work at Kensington.
High temperature carbon
Comet *b*, 1881.
Copeland.—'Copernicus,' vol. 2, p. 225.

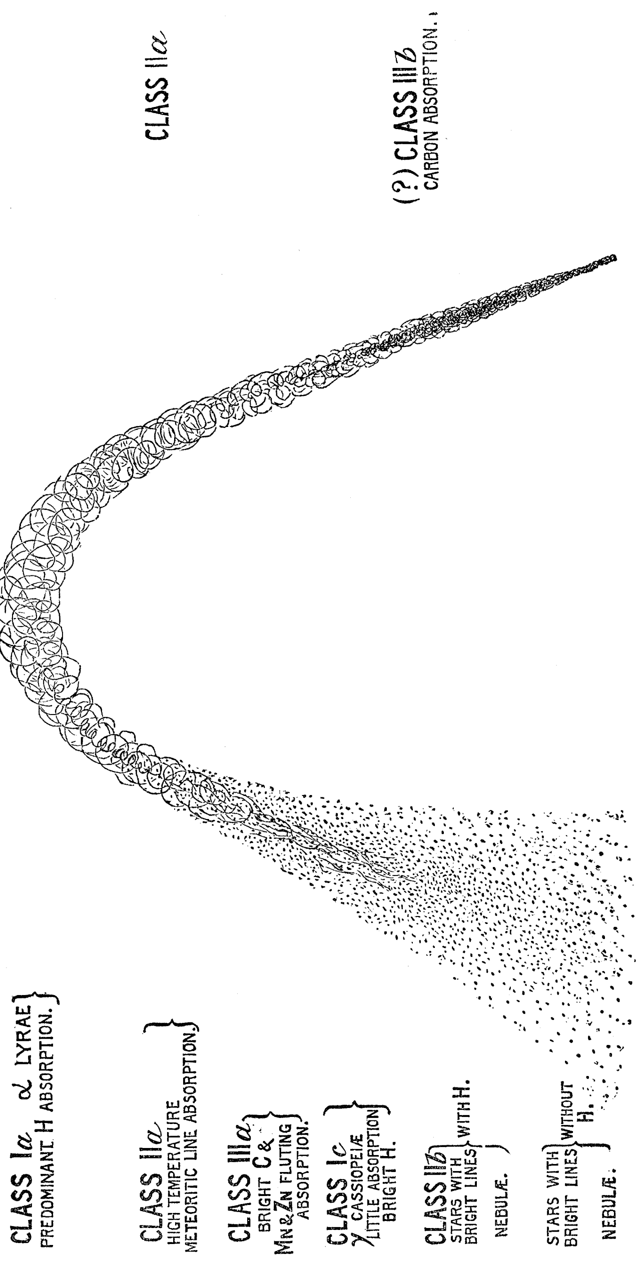
Manganese flame.
    Lecoq de Boisbaudran.—'Spectres Lumineux.'
    Work at Kensington.
Nova Orionis.
    Copeland.—'Monthly Notices of the Royal Astronomical Society,' vol. 46 p. 109.
α Orionis.
    Vogel.—'Beobachtungen zu Bothkamp,' Heft 1, p. 20.
R. Geminorum.
    Vogel.—'Astronomische Nachrichten,' No. 2000.
Meteorite Glow.
    Work at Kensington.
Schjellerup 152.
    Vogel.—'Publicationen des Astrophysikalischen Observatoriums zu Potsdam, vol. 4, No. 14, p. 30.

On the Absorption Phenomena of Stars with bright Lines.

In addition to the map showing the bright lines visible in those stars the spectra of which contain them, I have prepared another map showing the absorptions which also occur. The two maps present a remarkable agreement—that is to say, there is the same progression in the absorption phenomena as there is in the bright line phenomena. In those stars in which bright lines are seen without the lines of hydrogen (in which stars the meteorite swarm is probably at a slightly higher temperature than that observed in the nebula when only the line at 500 is visible) we have no marked absorption-lines, but rather bands. When the hydrogen lines are added, as in γ Cassiopeiæ, then we get the absorption of sodium and *b* of magnesium, as we should expect. The individual meteorites therefore are much cooler in these stars than in the Novas, seeing that the absorption is so little developed. Speaking generally, therefore, we may say that there are two causes of minimum absorption phenomena in stars. In the first place, as in the bright-line stars, only a little vapour surrounds each meteorite, and that vapour consists of the substances visible at the lowest temperature; while, on the other hand, in stars like Sirius, in consequence of the absolute state of vapour, we only get practically the absorption of hydrogen, or at all events the absorption of hydrogen in great excess, due, I have very little doubt, in part, to the fact that most other substances have been dissociated by the intense heat resulting from the condensation of the meteorites.

Notes on the Provisional Temperature Curve.

In order to bring the various results referred to in this communication in a definite form before my own mind, I have prepared a diagram which I have called a temperature curve, so that on one side of it we may consider those stages in the various heavenly bodies in



Temperature Curve (provisional).

which in each case the temperature is increasing, while on the other arm of the curve we have that other condition in which we get first vaporous combination, and then ultimately the formation of a crust due to the gradual cooling of the mass. At the top of such a curve we shall of course have that condition in which the highest temperature must be assumed to exist. In a letter to M. Dumas in the year 1872, I suggested that possibly the simplification of the spectrum of a star might be associated with the highest temperature of the vapour, and that idea seems to have been accepted by other observers since that time. We shall have then stars of the first class at the top of the temperature curve. On the one arm of the curve representing increasing temperature we shall have at various heights those aggregations which give us indications of a gradually increasing temperature brought about by collisions, beginning with meteorites as widely separated as they can be to *keep up* any luminosity at all, and finally vaporous condensations due to gravity.

On the arm of the curve descending from stars of the first class to dark bodies like, say, the companion to Sirius, we must place those bodies where absorption of compound molecules is indicated. This we find in stars of Class III*b* of Vogel. But here a very interesting question arises. Between stars of the first class and that of III*b* we are bound to insert stars of Class II, already located naturally on the ascending arm.

The Case of equal Temperatures on either Side of the Curve.

Speaking roughly, it may be said that the construction of such a curve as this suggests that similar or nearly similar temperatures will be found on either side. This in the main, of course, is true; but it must be pointed out that, on the rising curve, the temperature will be that, as a rule, of individual meteorites and the vapours given out by them, while on the descending arm it will be the temperature of the consolidated mass, whether vaporous or becoming solid. But it is obvious that if we take two points near the top of the curve we shall have very nearly the same temperature of the atmosphere, by which I mean the temperature of the layers in either case which are most effective in producing the phenomena of absorption. To take a concrete case, stars of the second class are obviously, by the consent of all, of a lower temperature than stars of the first class: on which side, therefore, of the curve must they be placed? Or, to take a more concrete case still, our sun is a star of the second class: on which arm of the curve must we place the sun? Here we find ourselves in a position of some difficulty, but it would appear that future work may enable us really to divide stars of the second class into two series, and if we can do so there is very little doubt that one series will represent the phenomenon of decreasing temperature of the ab-

sorbing layers, while the other series will represent the phenomenon of increasing temperature.

What considerations are likely to help us in such an inquiry as this? The atmosphere of a star built up by meteorites should resemble in its constitution the totality of the chemical constitution of meteorites, and therefore it might be inferred that the spectroscopic phenomena presented by such an atmosphere would not be widely different from the spectroscopic phenomena presented by the vapours of many meteorites volatilised together.

To investigate this question I have obtained composite photographs of the spectra of several meteorites, with a solar spectrum for purposes of comparison. I find that, while, on the one hand, the composite photograph giving us the spectrum of the meteorites greatly resembles that of the sun, as it should do, there are some variations which suggest the line of separation to which I have before alluded. From Dr. Huggins's magnificent photographs of the stars we have learned that, as I had predicted years before the photographs were taken, the thickness of H and K varies very greatly in different stellar spectra. In those stars, presumably the hottest ones, in which we get the series of hydrogen lines almost alone as great absorbers, K is almost absent; it finally comes in, however, and after a certain stage has been reached it is the most important line in the spectrum. But there are stars in which the lines *h* and G of hydrogen are not very much more developed than they are in the case of our own sun, in which K is much thinner than in the solar spectrum; and associated with this condition of K there is the absorption of a hydrogen line more refrangible than K at wavelength 3800, which is not represented in the solar spectrum with anything like the intensity. The question arises, therefore, whether the enormous thickening of K observed in the sun and some other stars may not be limited to those stars which, like our sun, are reducing their temperature; for we certainly are justified in assuming that the temperature of the sun now is not so high as it was in an earlier stage of the development of the system. Such a difference as that, if it is subsequently established, can only come from the atmosphere, as an effect of cooling, becoming richer in those substances the lines of which get broader as the star cools down. We can easily imagine that during the process of cooling the relative quantities of the vapours should not always remain constant, although it is impossible in the present state of our knowledge to give any particular reason why such and such vapours should disappear from the spectrum in consequence of chemical combinations, while others should develop apparently in consequence of their retirement.

Hydrogen plus Carbon indicates mixed Swarms.

If we assume a brightening of the meteor-swarm due to collision as the cause of the so-called new stars, we have good grounds for supposing that in these bodies the phenomena should be mixed, for the reason that we should have in one part of the swarm a number of collisions probably of close meteorites, while among the outliers the collisions would be few. We shall in fact have in one part the conditions represented in Class III*a*, and in the other such a condition as we get in γ Cassiopeiæ. I have in another part of this paper discussed the flutings observed in Nova Orionis, and have shown that so far as they were concerned we have the radiation of carbon and the absorption of manganese; but there is evidence to show that with these fluted appearances bright lines were observed —D_3 and F, although no mention is made of C.*

We have here, there is little doubt, the *vera causa* of stellar long-period variability. 12 per cent. of stars of Class III*a* are variable, and 9 per cent. of Class III*b*. In the one case, meteor-swarms produce the increased brightness by colliding with those of the condensing one. In the other, they do so by their periastron passage round the dim condensed one. There is no variability, in the usual sense of the word, in stars like the sun and α Lyræ, and the reason is now obvious.

The Conditions of Collisions of Meteorites.

The Chemical Elements most frequently determined in Meteorites.

I think it well to give here as a reminder a short table showing the chief substances met with in meteorites. It will indicate the cause of the continued reference to the spectra of Mg, Fe, and Mn in what follows.

Siderites.

Nickel-iron, copper, manganese.
Troilite = FeS.
Graphite.
Schreibersite = iron and nickel phosphide.
Daubréeite = iron and chromium sulphide.

Siderolites.

Chondritic—

(α) Non-carbonaceous = Olivine = chrysolite = peridot = $(Mg,Fe)_2O_4Si$ = SiO_2 41·3, MgO 50·9. FeO 7·7.

* Konkoly, 'Astr. Nachr.,' 2712, D_3 and F; Riccò indicates D_3 in 'Astr. Nachr.,' 2707.

	Enstatite $MgO_3Si = SiO_2$ 60, MgO 40.
	Bronzite = Enstatite, in which some Mg is replaced by Fe.
	Nickel-iron, manganese.
	Troilite.
	Chromite = iron protoxide 32, chromium sesquioxide 68, + Al and Mg.
	Augite = pyroxene, SiO_2 55, CaO 23, MgO 16, MnO 0·5, FeO 4.
	Silicate of calcium, sodium, and aluminium.
(β) Carbonaceous	Carbon in combination with H and O.
	Sulphates of Mg, Ca, Na, and K.
Non-chondritic—	
	Anorthite.
	Enstatite.
	Bronzite.
	Olivine.
	Augite.
	Troilite.

I. *The Numbers of Meteorites in Space.*

It is well known that observations of falling-stars have been used to determine roughly the average number of meteorites which fall on the earth each twenty-four hours; and having this datum to determine the average distance apart between the meteorites in those parts of space which are traversed by the earth as a member of the solar system, Dr. Schmidt, of Athens, from observations made during seventeen years, found that the mean hourly number of luminous meteors visible on a clear moonless night by one observer was fourteen, taking the time of observation from midnight to 1 A.M.

It has been further experimentally shown that a large group of observers who might include the whole hemisphere in their observations would see about six times as many as are visible to one eye. Professor H. A. Newton and others have calculated that making all proper corrections the number which might be visible over the whole earth would be a little greater than 10,000 times as many as could be seen at one place. From this we gather that not less than twenty millions of luminous meteors fall upon our planet daily, each of which in a dark clear night would present us with the well-known phenomenon of a shooting star.

This number, however, by no means represents the total number of minute meteorites that enter our atmosphere, because many entirely invisible to the naked eye are often seen in telescopes. It has been suggested that the number of meteorites if these were included would

be increased at least twenty-fold: this would give us 400 millions of meteorites falling on the earth's surface daily. If we consider, however, only those visible to the naked eye, and if we assume that the absolute velocity of the meteors in space is equal to that of comets moving in parabolic orbits, Professor H. A. Newton has shown that the average number of meteorites in the space that the earth traverses is in each volume equal to the earth about 30,000. This gives us a result in round numbers that the meteorites are distributed each 250 miles away from its neighbours.*

If, then, these observations may be accepted to be good for any part of space, we may, and indeed must, expect celestial phenomena which can be traced to meteorites in all parts of space.

Further, we have the experience of our own system that these meteors are apt to collect in groups.

A comet, it is now generally accepted, is a swarm of meteors in company. Such a swarm finally makes a continuous orbit by virtue of arrested velocities; impacts will break up large stones and will produce new vapours in some cases, which will condense into small meteoroids.

A meteorite in space under any of the conditions indicated by the comets, new stars, and such first-magnitude stars as α Orionis, will evidently be subject to collisions, but only to a greater number of collisions than those which must ordinarily occur if space is as full of meteorites as Professor Newton's calculations, from observations made on the earth, would naturally seem to indicate.

The Velocity of Luminous Meteors.

In spite of the difficulties which attend the observations necessary to determine the velocity of meteors entering our atmosphere, many observations have been made from which it may be gathered that the velocity is rarely under 10 miles a second or over 40 or 50. It is known that the velocities of some meteor-swarms are very different from those of others. Professor Newton, our highest authority on this subject, is prepared to consider that the average velocity may be taken to be 30 miles a second.

Result of Collisions.

If we take these velocities as representing what happens in other regions of space, and assume the specific heat of the meteorites to be 0·10, the increase in their temperature when their motions are arrested by impacts will be roughly as follows:—

* Article "Meteorites," Professor Newton, 'Encyclopædia Britannica,' 9th edition, vol. 16.

Velocity 1 mile per second			....	3,000° C.
,, 10	,,	,,	....	300,000
,, 20	,,	,,	....	1,200,000
,, 30	,,	,,	....	2,700,000
,, 60	,,	,,	....	10,800,000

It is clear, however, that we should under the conditions stated be more frequently dealing with grazes than collisions.

Comets due to Collisions of Meteorites.

The fact that comets are due to swarms of meteorites was first established by Schiaparelli in 1866, when he demonstrated that the orbit of the August meteors was identical with that of the bright comet of 1862.*

Nebulæ due to Collisions of Meteorites.

So far as I know the first suggestion that nebulæ were really in some manner associated with meteorites and not with masses of gas was made by Professor Tait in 1871.† I have used the suggestion in my lectures ever since, and it is now some years ago since I put it to an experimental test by showing that both the spectra of comets and nebulæ, so far as carbon and hydrogen were concerned, could be produced from a vessel containing the vapours produced by meteorites. More recently, M. Faye has stated in his works on the nebular hypothesis that the solar nebula may as probably have consisted of a cloud of stones as of a mass of gas. This view, however, has not been favoured by Dr. Huggins, who in his observations both on nebulæ and comets has inferred from the near coincidence of the line of 500 with the strong air line that we are probably in presence of nitrogen, or of a form of matter more elementary than nitrogen; the line at 373 being attributed by him also to some unknown form of hydrogen on account of its coincidence with one of the series of hydrogen lines in the ultra-violet observed in the spectra of stars of the first class.

"New Stars" due to Collisions of Meteorites.

The idea that the *Novas* which appear from time to time are due to collisions of meteorites was, I think, first advanced by myself in 1877, when I wrote in connection with Nova Cygni:—

* Letters to Father Secchi, printed in the 'Bollettino' of the Collegio Romano, and reproduced in 'Les Mondes,' vol. 13.

† "It seems to me that we have a series of indications of what (for want of a better phrase) may be called the *period of life* of a star or group; beginning with the glowing gases developed by impacts of agglomerating cold masses. (Planetary nebulæ and others irresolvable, such as those of Orion, Lyra, &c., where the spectrum consists of a very few bright lines only.)" (Professor Tait, 'Edinburgh Roy. Soc. Proc.,' 1871.)

"The very rapid reduction of light in the case of the new star in Cygnus was so striking that I at once wrote to Mr. Hind to ask if any change of place was observable, because it seemed obvious that, if the body which thus put on so suddenly the chromospheric spectrum were single, it might only weigh a few tons, or even hundredweights, and, being so small, might be very near us. Mr. Hind's telescope was dismounted, and I have not yet got any information as to the change of position; and as I am now writing in the Highlands, away from all books, I have no opportunity of comparing the position now given by Lord Lindsay in R.A. 21h. 36m. 52s., Decl. + 42° 16′ 53″, with those given on its first appearance by Winnecke and others.

"We seem driven, then, from the idea that these phenomena are produced by the incandescence of large masses of matter, because if they were so produced, the running down of brilliancy would be exceeding slow.

"Let us consider the case, then, on the supposition of small masses of matter. Where are we to find them? The answer is easy:—in those small meteoric masses which, an ever-increasing mass of evidence tends to show, occupy all the realms of space."*

The Effects of Collisions.

The question of what must happen to the meteorites themselves in consequence of this system of collisions is worth going into thoroughly. A very cursory examination seems to indicate that much light is thrown on the condition of meteorites as we know them, and their division into iron and stony.

As 30 miles per second is a very frequent value obtained for the velocity of meteorites when they enter our atmosphere, it is possible to compare temperatures brought about by collisions with those produced by passage through our atmosphere. Two masses of meteoric iron meeting each other in space would probably, if moving with a certain velocity, be formed into a pasty conjoined mass, and this process might go on until an iron of large dimensions was formed, and the various meteorites thus welded together would present in time a very fragmentary appearance. While irons were thus increasing in size, collisions with smaller meteorites would be attended with very local increases of temperature, perhaps sufficient to volatilise the surface or allow it to be indented, and in this manner the well-known "thumb-marks" receive explanation.

The masses of iron, when in a state of fusion, whatever their size, would be able to include stony meteorites in their vicinity. In the case of stones it is easy to see that the result would be very different. Their collisions would have, most probably, the effect of reducing large pre-existing masses to smaller ones, and the collision of a large

* 'Nature,' vol. 16, p. 413.

stone with a large iron would probably effect the driving of the stone into fragments, while the iron would be liquefied so as to inclose some of the fragments in its mass.

These operations of Nature might go on either in free space, or in the head of a comet, or in meteor-swarms. They probably cause the appearance of the so-called new stars, and in these various circumstances the rate of subsequent cooling would of course be very different, so that the results would be very different indeed.

Large masses on collision probably destroy each other, produce fragments and vapour, which again condense. The heterogeneous structure is thus to a certain extent explained. On collision the part of the substance of the meteorite given up will depend on the temperature, and thus a mass of metallic iron mixed with silicates at low temperature will get rid of the iron at once, which must then perforce condense in a separate swarm; therefore under low temperature conditions, say at aphelion, irons alone will be formed and the stones will become spongy. The stones will absorb the carbon and hydrogen vapours.

General Conclusions.

The general conclusions to which the foregoing investigations lead may thus be stated :—

I. All self-luminous bodies in the celestial spaces are composed of meteorites, or masses of meteoritic vapour produced by heat brought about by condensation of meteor-swarms due to gravity.

II. The spectra of all such bodies depend upon the heat of the meteorites, produced by collisions, and the average space between the meteorites in the swarm, or in the case of consolidated swarms, upon the time which has elapsed since complete vaporisation.

III. The temperature of the vapours produced by collisions in nebulæ, stars without C and F but with other bright lines, and in comets away from perihelion, is about that of the bunsen burner.

IV. The temperature of the vapours produced by collision in α Orionis and similar stars is about that of the Bessemer flame.

V. The line of increase of temperatures of the swarms of meteorites and subsequent cooling of the mass of vapour produced, and the accompanying phenomena, may be provisionally stated as follows :—

Sequences of Spacing and Temperatures (Provisional).

From Cold to Hot = Sparse to Dense Swarms.

	Spectrum of interspace.		Spectrum of vapour of meteorite.		Spectrum of meteorite.
	H.	C.	Radiation.	Absorption.	Radiation.
Nebulæ (without F)	Nil	Nil	Mg (500) ± 495	Nil	Dimly discontinuous.
Comets 1866 and 1867	Nil	Nil	Mg (500)		
Nova Cygni after collision	Nil	Nil	Mg (500)		
Stars with bright lines (without F)	Nil	Nil	Fe, Mn	Broad band 475	
Nebulæ (with F)	H	Nil	Mg (500) ± 495	Nil	Continuous.
Stars with bright lines (with F)	H	Nil	Fe, Mn	D, *b*, and other lines and bands	
Comets under mean conditions of collision	Nil	C	Mg(*b*)	Nil	Continuous.
Comets at perihelion	Nil	C	Meteorite lines	(?)	
Stars, Class III*a*	Nil	C	......	Meteorite flutings and lines	Vividly continuous.
Mixed swarms—					
R. Geminorum	H	C	Meteorite lines	Meteorite lines.	
Nova Orionis at maximum	H	C	......	Meteorite flutings and lines.	
Condensation.					
Stars, Classes I and II			Continuous	High temperature lines of substances present in meteorites	The radiation from individual meteorites now gives place to radiation from the interior vaporous and subsequently consolidated mass of the condensed swarm.
Subsequent Cooling.					
Stars: Class II, some stars, including the Sun			Continuous	K in excess	
Stars: Class III*b*				Flutings of carbon	

VI. The brilliancy of these aggregations, at each increasing temperature, depends on the number of meteorites in the swarm, *i.e.*, the difference depends upon the quantity, and not the intensity, of the light.

VII. The existing distinction between stars, comets, and nebulæ rests on no physical basis.

VIII. The main factor in the various spectra produced is the ratio of the interspaces between the meteorites to their incandescent surface.

IX. When the interspace is very great, the tenuity of the gases given off by collisions will be so great that no luminous spectrum will be produced ("nebulæ" and "stars" without F bright). When the interspace is less, the tenuity of the gas will be reduced, and the vapours occupying the interspaces will give us bright lines or flutings ("nebulæ" and "stars" with F bright). When the interspace is relatively small, and the temperature of the individual meteorites therefore higher, the preponderance of the bright lines or flutings in the spectrum of the interspaces will diminish, and the incandescent vapour surrounding each meteorite will indicate its presence by absorbing the continuous spectrum-giving light of the meteorites themselves.

X. The brighter lines in spiral nebulæ, and in those in which a rotation has been set up, are in all probability due to streams of meteorites, with irregular motions out of the main streams, in which the collisions would be almost *nil*. It has already been suggested by Professor G. H. Darwin*—using the gaseous hypothesis—that in such nebulæ "the great mass of the gas is non-luminous, the luminosity being an evidence of condensation along lines of low velocity, according to a well-known hydrodynamical law. From this point of view the visible nebula may be regarded as a luminous diagram of its own stream-lines."

XI. New stars, whether seen in connexion with nebulæ or not, are produced by the clash of meteor-swarms, the bright lines seen being low-temperature lines of elements the spectra of which are most brilliant at a low stage of heat.

XII. Most of the variable stars which have been observed belong to those classes of bodies which I now suggest are uncondensed meteor-swarms, or condensed stars in which a central more or less solid condensed mass exists. In some of those having regular periods the variation would seem to be partly due to swarms of meteorites moving around a bright or dark body, the maximum light occurring at periastron.

XIII. The spectrum of hydrogen seen in the case of the nebulæ seems to be due to low electrical excitation, as happens with the

* 'Nature,' vol. 31, p. 25.

spectrum of carbon in the case of comets. Sudden changes from one spectrum to the other are seen in the glow of meteorites in vacuum tubes when a current is passing, and the change from H to C can always be brought about by increased heating of the meteorite.

XIV. Meteorites are formed by the condensation of vapours thrown off by collisions. The small particles increase by fusion brought about again by collisions, and this increase may go on until the meteorites may be large enough to be smashed by collisions, when the heat of impact is not sufficient to produce volatilisation of the whole mass.

XV. Beginning with meteorites of average composition, the extreme forms, iron and stony, would in time be produced as a result of collisions.

XVI. In recorded time there has been no such thing as a world on fire, or the collision of masses of matter as large as the earth, to say nothing of masses as large as the sun; but the known distribution of meteorites throughout space indicates that such collisions form an integral part of the economy of nature. The number of bodies, however, subject to such collisions is extremely small, and must, it would appear, form but a small percentage of the celestial bodies, seeing that they must be dark and cold.

XVII. *Special Solar Applications.*

α. The solar spectrum can be very fairly reproduced (in some parts of the spectrum almost line for line) by taking a composite photograph of the arc spectrum of several stony meteorites, chosen at random, between iron meteoric poles.

β. The carbon which originally formed part of the swarm the condensation of which produced the solar system, has been dissociated by the high temperature brought about by that condensation.

γ. The indications of carbon which I discovered in 1874 ('Roy. Proc. Soc.,' vol. 37, p. 308) will go on increasing in intensity slowly, until a stage is reached when, owing to the reduction of temperature of the most effective absorbing layer, the chief absorption will be that of carbon—a stage in which we now find the stars of Class III*b* of Vogel's classification.

δ. At the present time it seems probable that among the chief changes going on in the solar spectrum are the widening of K and the thinning of the hydrogen lines.

I have finally to express my great obligations to Messrs. Fowler, Taylor, and Richards, who have helped me in various ways in the researches embodied in this paper. Mr. Fowler, the assistant to the Solar Physics Committee, has made most of the observations on meteorites, and low-temperature spectra generally, which have been

recorded on the maps, and he has carried out this work with a care, skill, and patience beyond all praise. The observations have in nearly every case been checked also by myself. Mr. Taylor, the Demonstrator of Astronomy, has been chiefly responsible for looking up the literature and mapping the results, in which he has been aided by Mr. Richards.

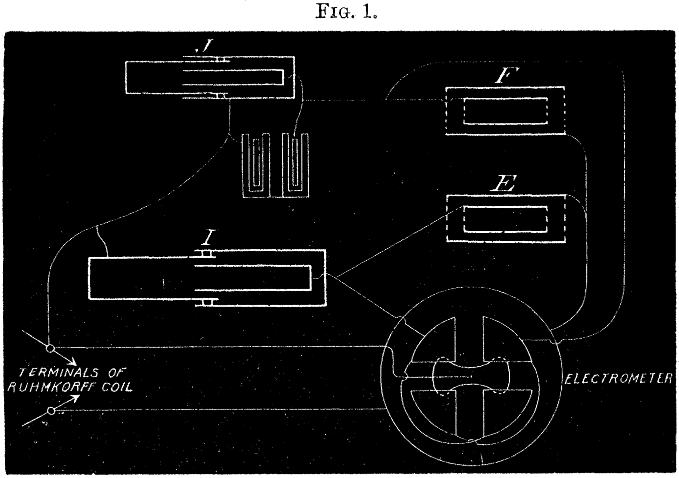
II. "Specific Inductive Capacity." By J. Hopkinson, M.A., D.Sc., F.R.S. Received October 14, 1887.

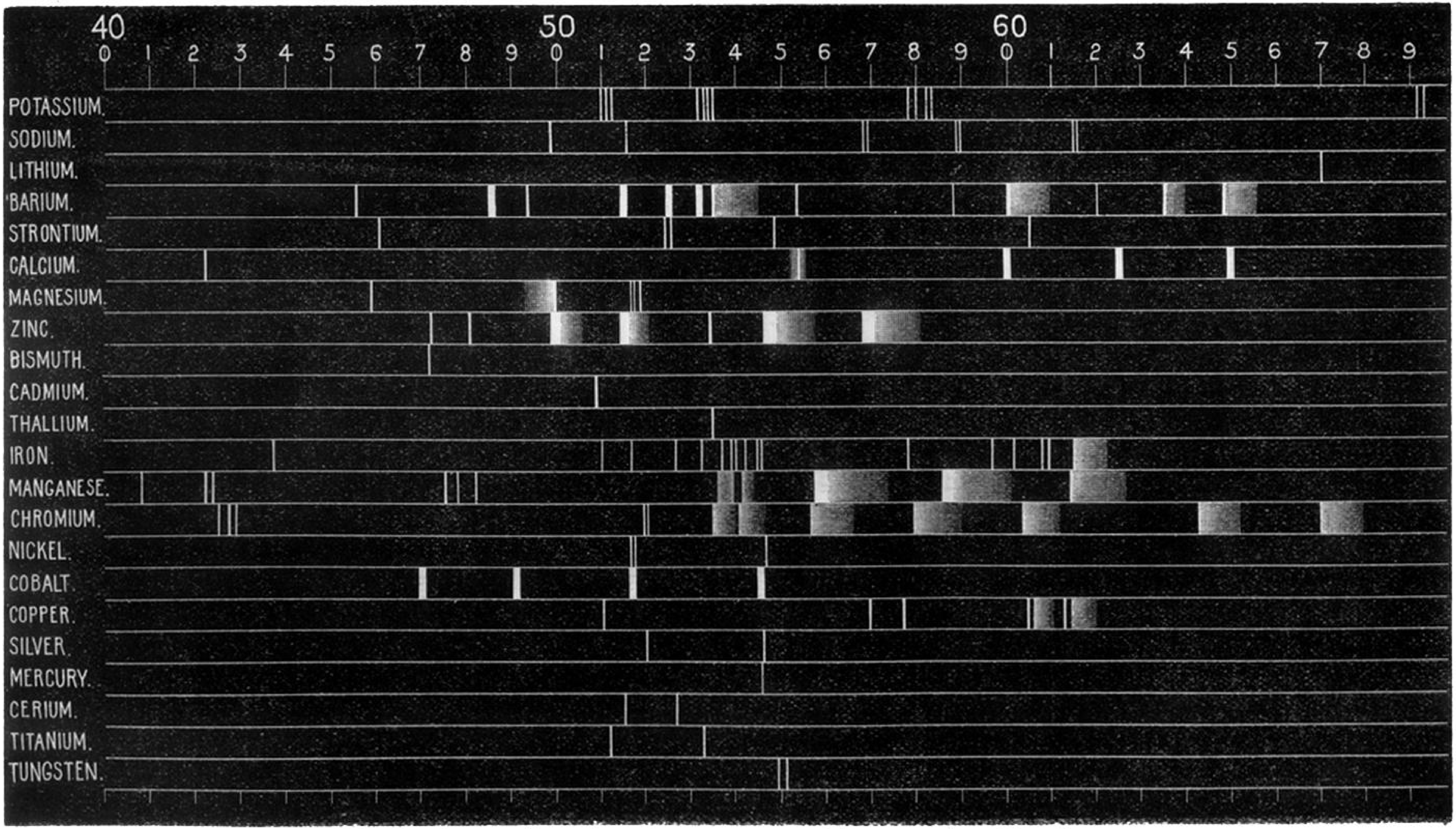
The experiments which are the subject of the present communication were originally undertaken with a view to ascertain whether or not various methods of determination would give the same values to the specific inductive capacities of dielectrics. The programme was subsequently narrowed, as there appeared to be no evidence of serious discrepancy by existing methods.

In most cases the method of experiment has been a modification of the method proposed by Professor Maxwell, and employed by Mr. Gordon. The only vice in Mr. Gordon's employment of that method was that plates of dielectrics of dimensions comparable with their thickness were regarded as of infinite area, and thus an error of unexpectedly great magnitude was introduced.

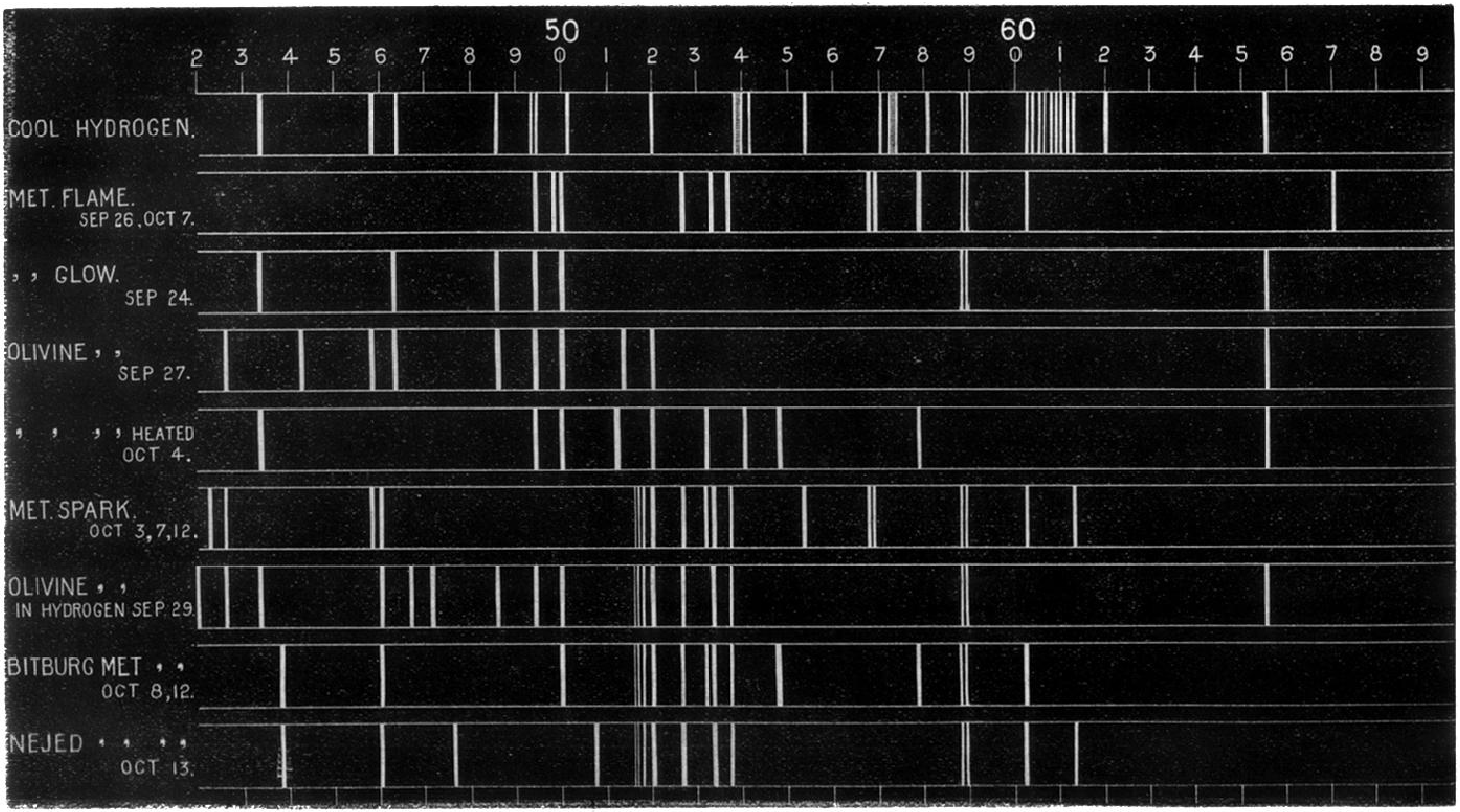
For determining the capacity of liquids, the apparatus consisted of a combination of four air condensers, with a fifth for containing the liquid arranged as in a Wheatstone's bridge, fig. 1. Two, E, F, were

Fig. 1.



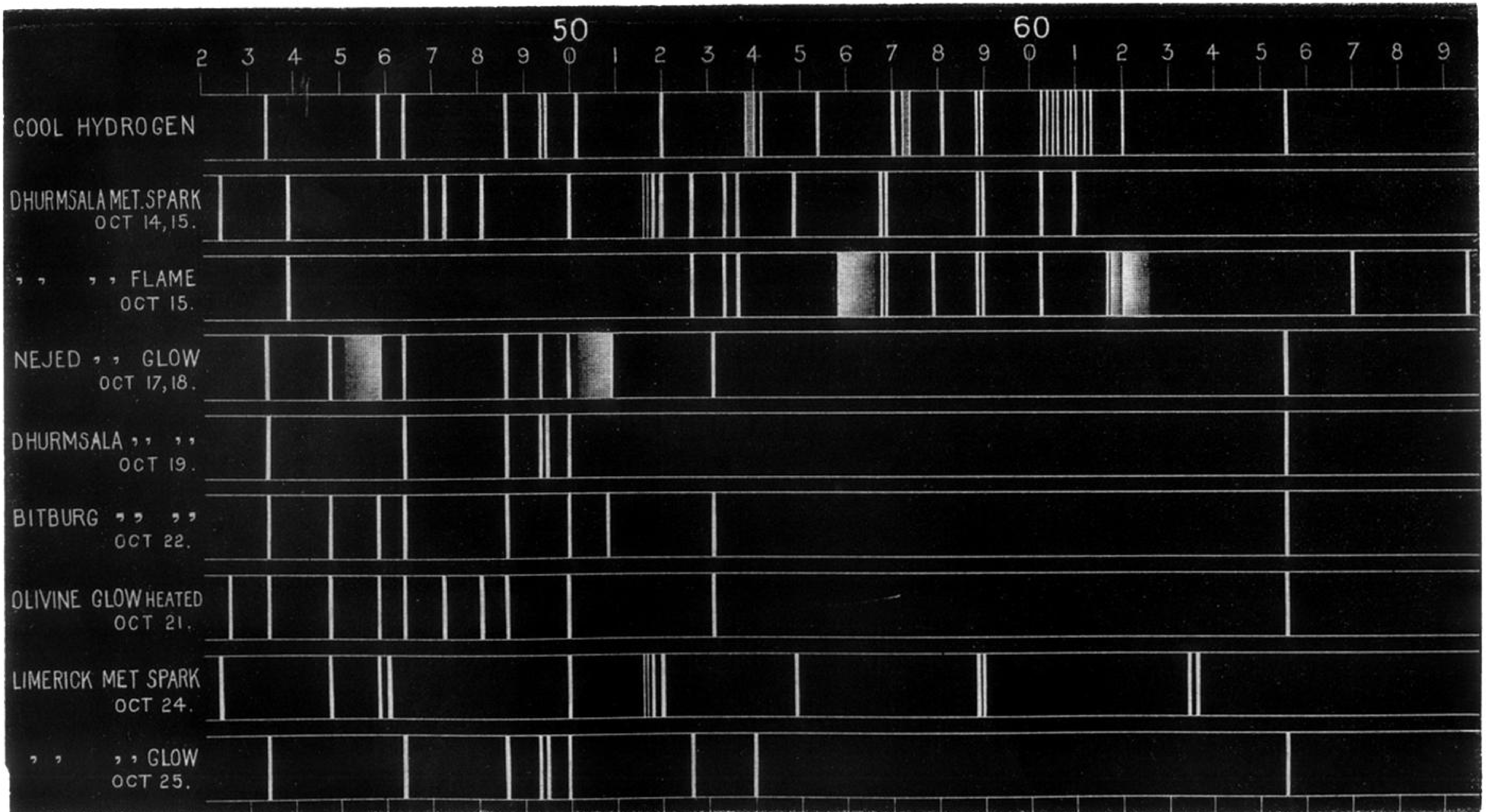


MAP I.—Spectra of metals at the temperature of the oxy-coal-gas blowpipe.

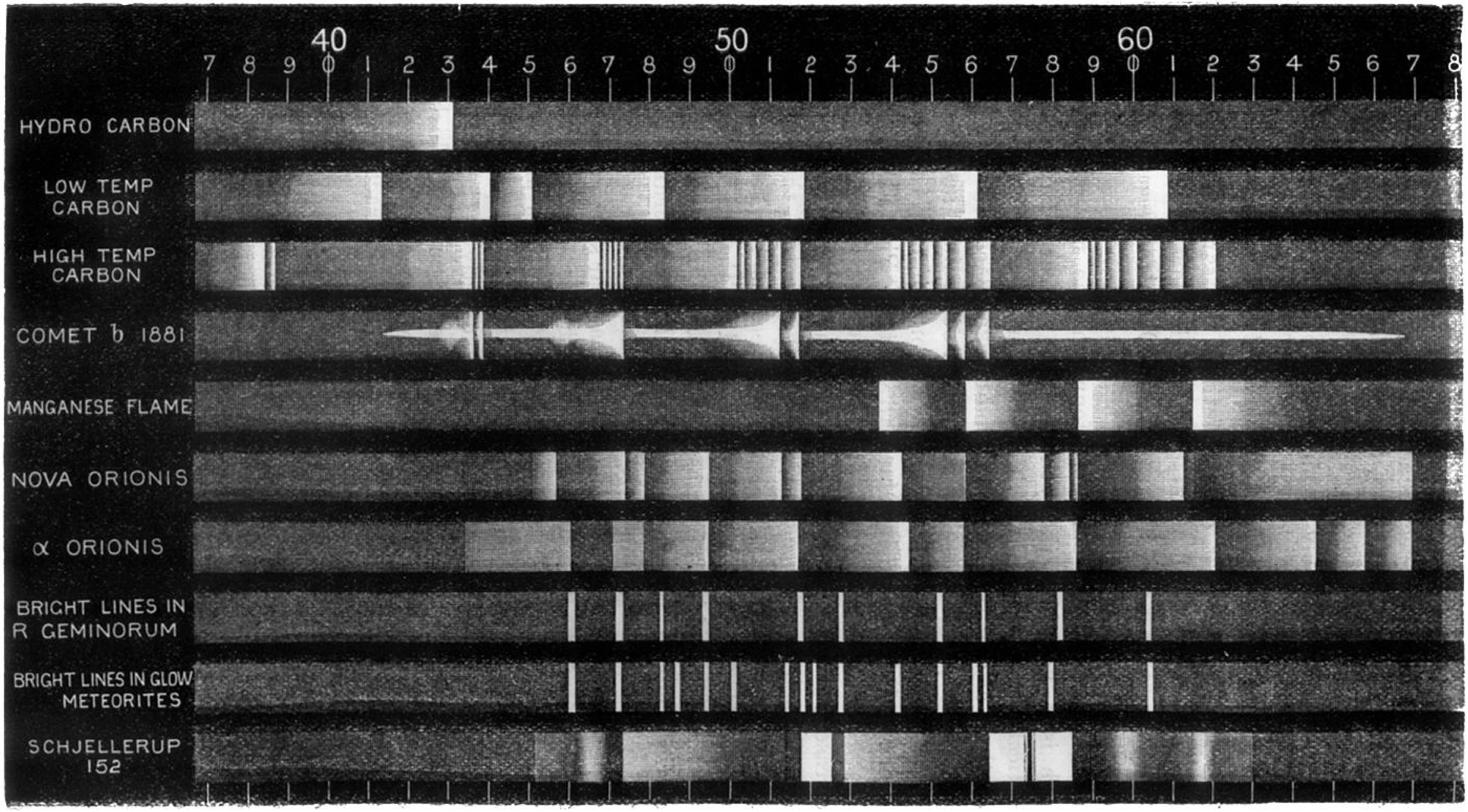


50
60
2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9
COOL HYDROGEN.
MET. FLAME.
SEP 26, OCT 7.
,, GLOW.
SEP 24.
OLIVINE ,,
SEP 27.
,, ,, ,, HEATED
OCT 4.
MET. SPARK.
OCT 3, 7, 12.
OLIVINE ,,
IN HYDROGEN SEP 29.
BITBURG MET ,,
OCT 8, 12.
NEJED ,, ,,
OCT 13.

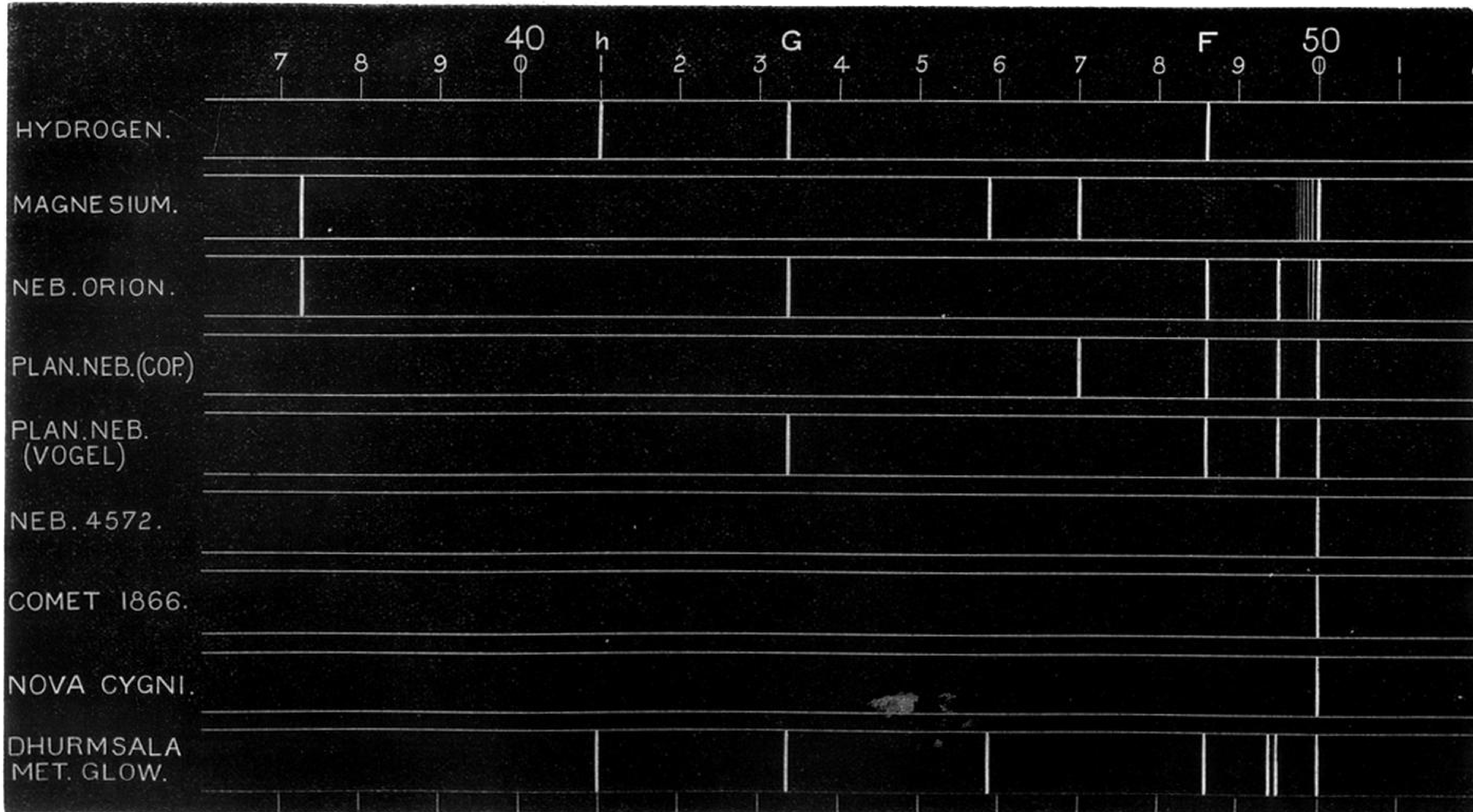
Map 2.



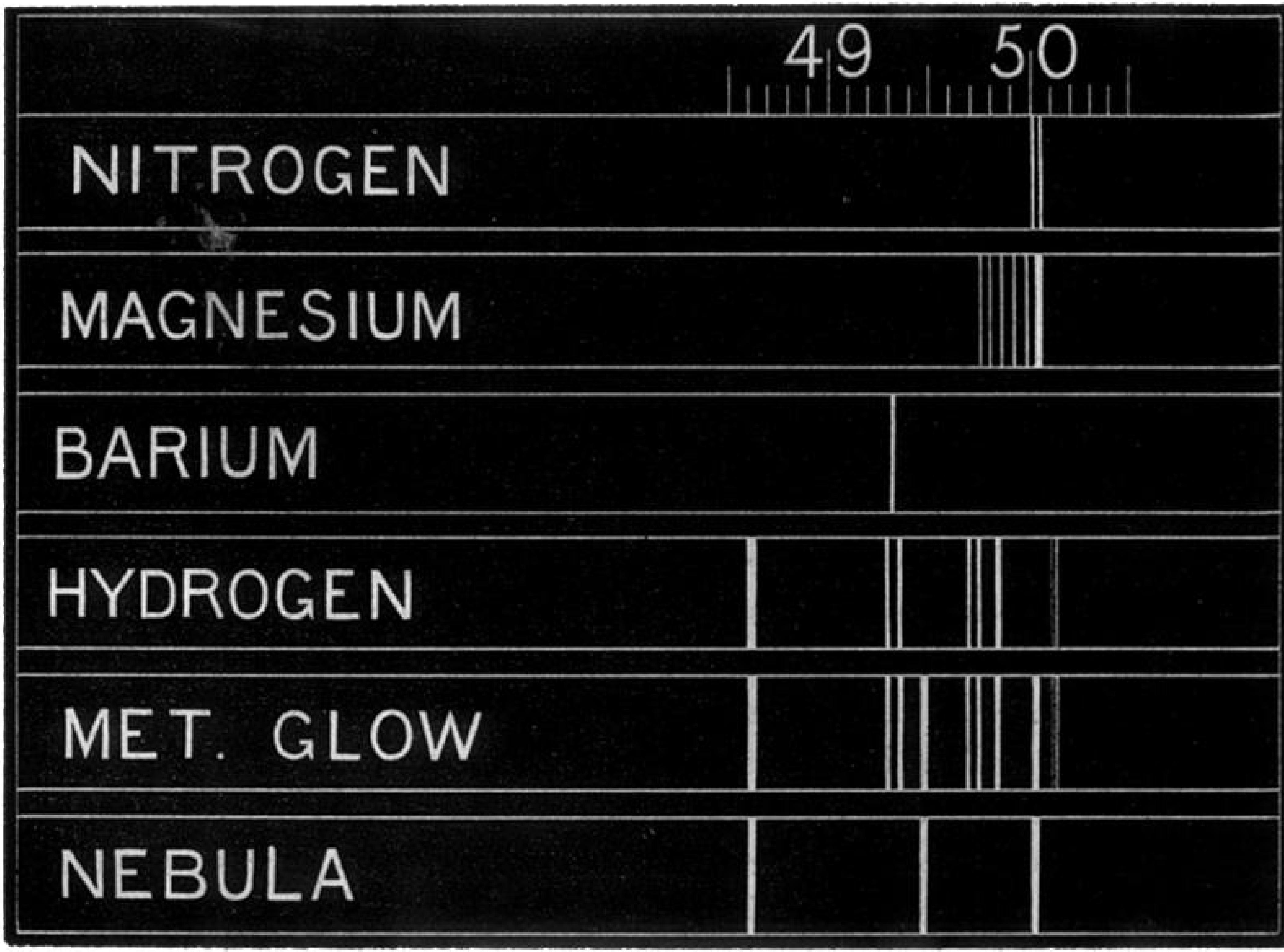
MAP 2A.—Spectra of Olivine and Meteorites under various conditions.



MAP 3.—Comparison of flutings seen in the spectra of "stars" and comets, with flutings of carbon, manganese, and zinc, and in the case of R. Geminorum lines with remnants of flutings and lines seen in a meteorite glow. (The Zn fluting is at λ 544 in α Orionis.)



MAP 4.—Spectra of nebulæ compared with the spectra of hydrogen, cool Mg, and meteorite glow.



MAP 5.—Diagram showing the positions of the nebula lines as compared with lines of N, Mg, Ba, H, and meteorite glow.